PAPERS OF THE
ROBERT S. PEABODY FOUNDATION
FOR ARCHAEOLOGY

VOLUME FOUR · NUMBER ONE

THE BOYLSTON STREET FISHWEIR II

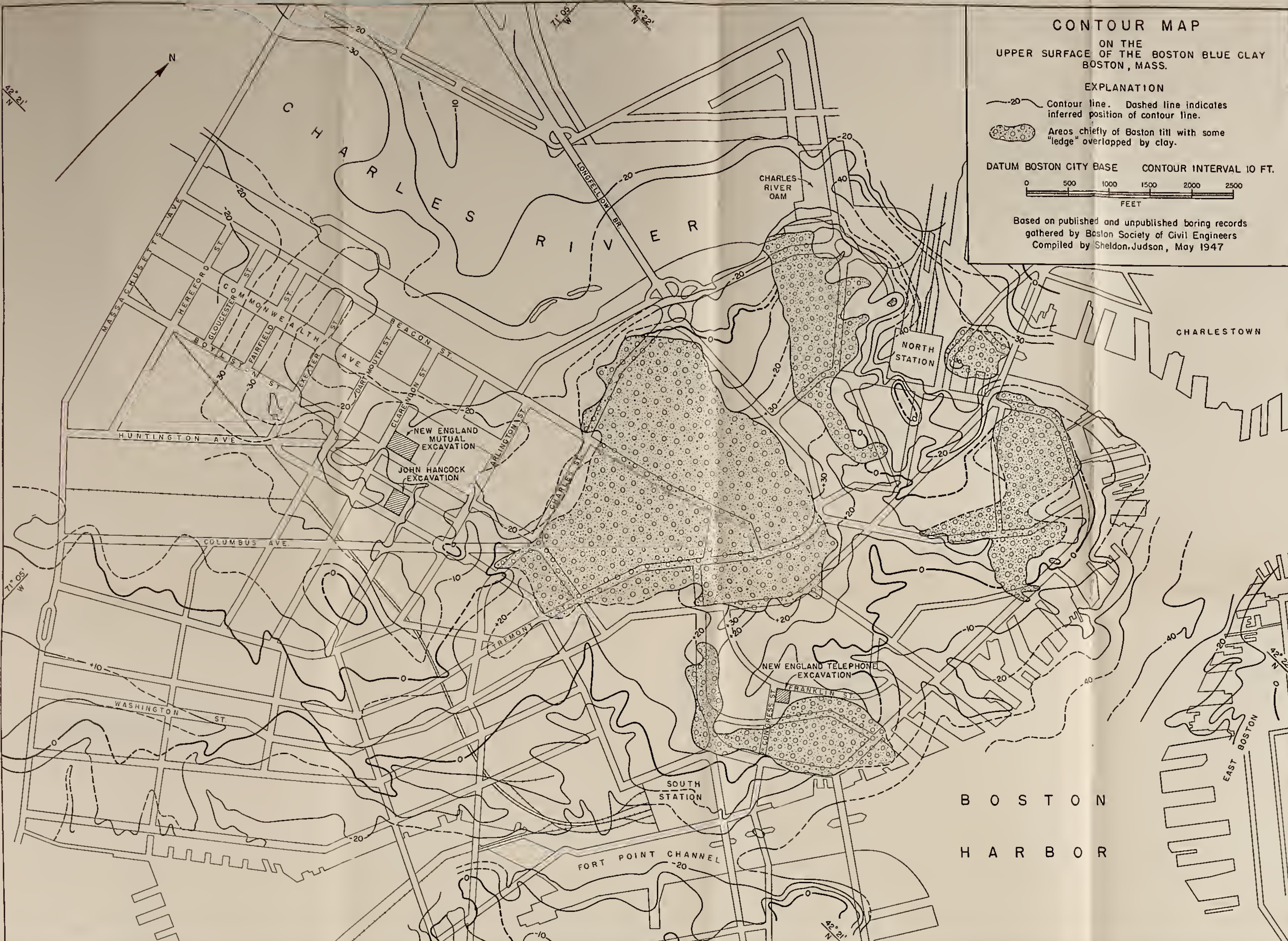
A STUDY OF THE GEOLOGY, PALAEOBOTANY, AND BIOLOGY OF A SITE ON STUART STREET IN THE BACK BAY DISTRICT OF BOSTON, MASSACHUSETTS

BY
Elso S. Barghoorn, Paul S. Conger, Sheldon Judson,
Fred B. Phleger, L. R. Wilson

EDITED BY

Frederick Johnson

PHILLIPS ACADEMY · ANDOVER, MASSACHUSETTS
PUBLISHED BY THE FOUNDATION
1949



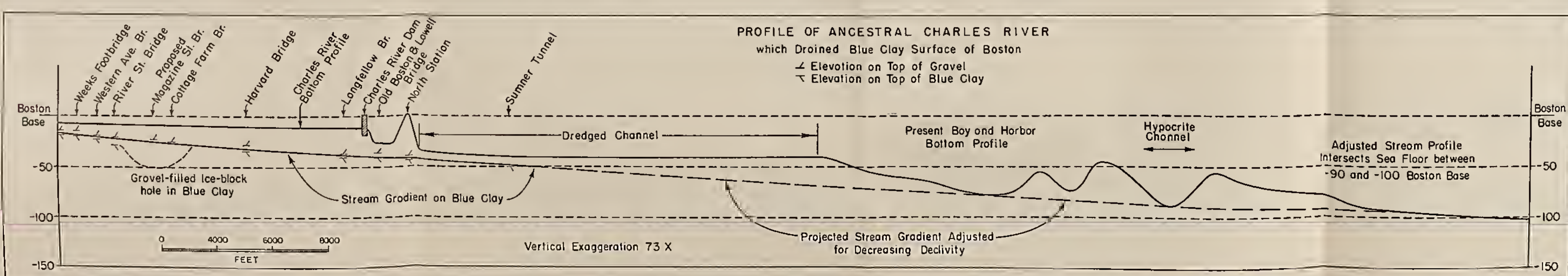


Fig. 1-*a*. Contour Map on the Surface of the Boston Clay.

Fig. 1-*b*. Projection of Stream Gradient on the Surface of the Boston Clay.

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PRINTED BY
CRIMSON PRINTING COMPANY
CAMBRIDGE, MASSACHUSETTS

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PREFACE

THIS study is presented for the purpose of clarifying and adding to analyses which began in 1939. The results of earlier work were published in 1942. At this time the researches were somewhat hampered by the lack of precedent as to method. In 1939 a general problem of great scope was stated but the method and direction of attack had to be determined by requirements of various phases of the analyses. As a result, some lines of reasoning and experiment led into blind alleys and had to be discarded, others developed in pretty much unpredictable fashion. At the time of publication several aspects of the problem had been investigated with some thoroughness but others had either been slightly touched upon or simply suggested. Some progress was made, but obviously, and perforce, much was left undone. Therefore, when a nearby deep excavation in the Back Bay region was opened for the purpose of constructing a building for the John Hancock Life Insurance Company, we seized the opportunity to continue the work.

Here we have the pleasure of presenting a considerable quantity of new data. Previous discussions of the geology of the region are superseded by a more valid study which includes a larger region and data from a core extending to bed rock one hundred and nine feet below the site. The collection of more adequate samples has made possible a surer interpretation of the pollen spectra and the distribution of diatoms and foraminifera. The peat has been given far more attention than was possible previously and the discovery of strata, including the stumps of an early forest, either not present or unrecognized at the first site has provided additional significant data.

One of the pleasantest duties which accompanies the compilation of a report of this kind is the acknowledgement of the contributions of many sorts. For practical reasons this study was an arduous one. The work had to be done when the excavation was open; there was no opportunity to reorganize or arrange research schedules. Without a murmur the collaborators took up their tasks, sometimes at most inconvenient and awkward times. The accomplishments of these men comprise the major portion of this monograph and to them the Peabody Foundation and I owe a debt which will be hard to repay. All of us are grateful to Dr. Kirk Bryan who, from the outset, in 1939, has taken an interest in the problem. There is

no doubt that his visits to the excavation and the ensuing lengthy conversations have contributed much to the success of the endeavor.

There is an unfounded tradition to the effect that scientific work and modern business have difficulty maintaining relationships. In the present endeavor, at least, nothing could be further from the fact. Mr. Paul L. Cummings, Construction Consultant of the John Hancock Life Insurance Company was most cordial. To him and to his company we are obliged for gracious permission to pursue our investigations in the building excavation. The company's Clerk of the Works, Mr. Raphael Pitcher, took a personal interest in our project, so materially aiding the work. As in the past, the Turner Construction Company was most cooperative. Mr. M. H. Parsons, who was in charge of the John Hancock project on Stuart Street, did everything he could to be of help, as did Messrs. R. B. Hazard, Robert Egelhoff, and all the men under them. We were even permitted to engage the Raymond Concrete Pile Company to drill and remove a core from the site. In addition we were supplied with as much information as we requested. Similarly, Mr. G. M. Reeves, Project Manager of the Turner Construction Company at the site of the New England Telephone and Telegraph Company building, welcomed us many times, and personally showed us some of the significant features which his men had uncovered.

Lastly, but by no means least, we have an obligation to the Viking Fund which, through Dr. Paul Fejos, Director of Research, made a generous grant to meet that part of the cost of the boring and laboratory work which the budget of the Peabody Foundation could not afford.

FREDERICK JOHNSON

THE BOYLSTON STREET FISHWEIR II

INTRODUCTION

ON three occasions, in 1913, 1939, and 1946, vertical stakes, certainly sharpened with axes of some sort, and horizontal brushwood have been exposed in excavations to depths of forty feet or more below the present surface of the Back Bay district in Boston. Each discovery has attracted the attention of scholars who have published a number of analyses of the stakes and the materials which surround them. As a result, various problems and hypotheses have been posed.

From the beginning, the assemblage of stakes and wattles has been called a fishweir. In 1942, we pointed out that this inference could not be proved. The weight of circumstantial evidence that the stakes are actually parts of fishweirs materially increased with Judson's description, in the present publication, of the Back Bay of "Fishweir Time." That such a bay was present is substantiated by the findings of Barghoorn, Wilson and others. The stakes are found along the shores of this bay (Fig. 13) just where fishweirs are normally located. Examination of the map raises the question whether the remains of several weirs have not been found. At this writing it seems most probable that this is the case. It is likely that weirs were built to last a few seasons and that they were remodeled or moved up and down the shores as the changes in the bottom or local currents affected the run of the fish.

If this present opinion is true, the title of this paper is something of a misnomer. The fishweir here described is located in the northeastern section of the block on Berkeley Street between Stuart Street and St. James Avenue and properly should be called the Stuart Street Fishweir. The old name has been retained, however, for practical reasons. Since the situation of the present discovery in the cross section is nearly identical to that described on Boylston Street, it is believed that retention of this name will facilitate reference to and inclusion in the slowly growing literature concerning the sites.

In the present study we present data very similar in nature to that assembled in 1942. However, it has been possible to add a considerable amount of new data and to expand upon the old. The sediments exposed on Stuart Street and at other locations in the neighborhood of the Boston Basin are placed in a geologic sequence which includes much of eastern Massachusetts.

Biological work has confirmed previous investigations and added considerable detail. The identification of the foraminifera is more complete than formerly and the work on the diatoms and pollen, in some instances, add detail or expand interpretations. Perhaps a major contribution is the study of the peat, which has been the concern of several, and in which Barghoorn has been mainly preoccupied. His meticulous and ingenious analyses have many ramifications. The generalizations of stratigraphic and ecological nature which he has stated are, interestingly enough, confirmed by the other studies.

All the papers in this volume are directed at problems rising from the presence of the fishweir itself. However, they do have considerable significance in specific scientific fields. Barghoorn's paper is an outstanding example of this. His study of the peat is a necessary addition to our knowledge of the deposits in Boston. The results also must be considered and understood by all who work with peat, whatever may be the subject of their investigations. The second part of this paper investigates the degradation of plant tissues and the physical and chemical changes attending preservation and degradation of the plant cell wall. This is a highly specialized analysis which has no direct bearing upon the usual questions asked concerning the fishweir. However, when studies of this nature have been carried to the point where they can contribute directly to other kinds of analyses the significance of the section can be applied more broadly.

One source of data which is new to the study of the location of the fishweirs is the core of sediments which was removed from the site. This has made possible a surer geologic study and has provided additional materials to be searched for pollen, diatoms, and formaminifera. The results of some of these studies are included here. Other studies of this core will, we expect, appear in a supplement to this report. Some description of this core is necessary so that various references may be the more clear.

The boring was done by the Raymond Concrete Pile Company in June, 1946, the results being reported to us on July tenth. Shelby tubes two inches in diameter and three and one half feet long were used. These tubes are essentially pieces of pipe which are shoved down into the sediments in a manner which fills them with a section which is preserved in its proper vertical sequence. The tubes were sealed by Judson and me immediately after they were removed from the ground. The tubes were then numbered in sequence beginning at the top. In the laboratory the tubes were cut into six inch lengths which were lettered A, B, C, etc., beginning at the top of the tube. After the contents were carefully pushed out of these sections, they were cut lengthwise into quarters and placed in bottles. Sets of these

were distributed to Wilson, Phleger, and Conger. Judson retained one set for his own use.

Perhaps the major contribution of this study is the fact that it is a collaboration among several scientific disciplines. It has been heartening to watch the collaboration grow, for it fell into a loosely organized pattern composed of a number of basic ideas, the most important of which may be the concept of stratification. This pattern, in part outlined during the work leading to the 1942 publication, may be responsible for the general theme which runs through all the papers. Although ideas have been freely exchanged by the present collaborators, the occasion for long and lively discussion such as took place in the past has not arisen. In spite of the minimum of intimate contact, we present here a closely knit study which is a demonstration of the fact that traditional barriers between scientific fields are, in the end, figments of the imagination.

FREDERICK JOHNSON

THE PLEISTOCENE STRATIGRAPHY OF BOSTON, MASSACHUSETTS AND ITS RELATION TO THE BOYLSTON STREET FISHWEIR

SHELDON JUDSON

GENERAL STATEMENT

THE Boylston Street Fishweir occupies a limited and well-defined stratigraphic position within the Pleistocene[1] sediments of the Back Bay area of Boston. Deposition subsequent to the time of weir construction and operation has not only entombed this structure but has obliterated or largely obscured the physical details of the landscape that existed when the Fishweir was built. These deposits, as well as those laid down prior to the construction of the weir, form a sequence of deposits and inferred events which can be recognized at many localities throughout Boston and vicinity. This succession in turn bears a relation, as yet inadequately known, to the general events of the Pleistocene.

The following study touches briefly on the geography and the pre-Pleistocene geology of the area. The Pleistocene stratigraphy of Boston and vicinity is described in detail. The sequence of events at the site of the weir is reviewed and related to the areal sequence. The correlation of the Pleistocene stratigraphy of the Boston area with Pleistocene stratigraphy elsewhere is discussed. A reconstruction of the physical environment during Fishweir time is presented and some of its implications relative to the weir are considered. The area in which habitation sites of the people who built the weir are most likely to be preserved has been determined and is shown on a map. Finally, the possibility of dating the weir on the geologic data is reviewed.

[1] Following R. F. Flint (1947, pp. 209, 210) Pleistocene is here used to include all of post-Pliocene time. The terms 'recent' and 'postglacial' are used only in an informal and local sense.

PREVIOUS WORK

Johnson has reviewed the Pleistocene history of Boston and vicinity.[2] His summary, based largely upon the literature, has served to point up the inadequacy of our knowledge of the Pleistocene in this area. The paucity of information is understandable when one considers the difficulties of investigation of deposits. The great bulk lie below sea level. Others lie beneath "made" land or under the buildings and streets of the city. Nevertheless a considerable amount of data has been collected by many geologists and is recorded in the literature. These data have proved useful and will be referred to at appropriate points in this report.

GEOGRAPHY

The Fishweir is located in the estuary at the mouth of the Charles River, and thus in the Boston Lowland which is coincident with the geologic structure known as the Boston Basin. The Boston Lowland is bounded on the east by the shores of Boston Bay. Both to the north and south, hills 200 to 350 feet in height rise abruptly from the Lowland. To the west, the Lowland rises gradually to the level of the surrounding hills. It extends from Lynn on the north to Weymouth on the south. Re-entrants of the Lowland enter the highlands along the upper reaches of the Charles and Neponset Rivers. The extent of the Boston Lowland and its relation to the surrounding country may be seen in Figure 2.

PRE-PLEISTOCENE GEOLOGY

In general, the Boston Lowland and Basin is underlain by sedimentary and effusive igneous rocks of Permo-Carboniferous age. The highlands to the north, west, and south are chiefly older igneous and metamorphic rocks. Structurally, the Basin consists of a series of eastward plunging anticlines and synclines cut by both thrust and tear faults produced on the northeast limb of a tectonic arc, the greatest pressure being directed from southeast to northwest along a line southwest of Boston.[3] Subsequent to deformation of the Basin at the end of the Paleozoic, the geologic record is all but missing until the Pleistocene. Igneous activity, presumably of Triassic age, produced numerous diabase dikes. Sediments, possibly of Cretaceous age, have been reported from deep borings in Boston.[4]

[2] Johnson, et al., 1942.

[3] Billings, 1929, pp. 130-133. [4] Clapp, 1907.

BEDROCK TOPOGRAPHY OF THE BOSTON AREA

The bedrock topography which underlies the Pleistocene sediments of Boston and vicinity was first described and mapped in some detail by W. O. Crosby, and subsequently revised by I. B. Crosby.[5]

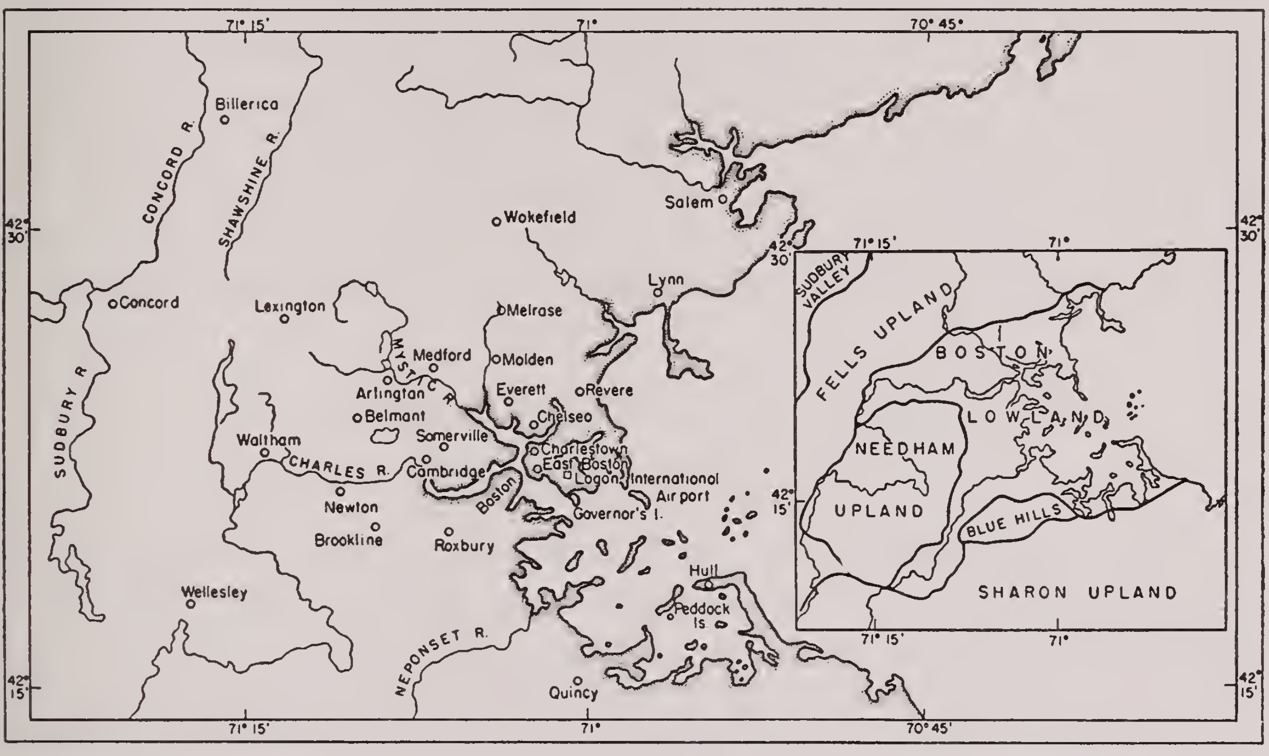


FIG. 2. Index map. Insert of Geomorphic Subdivisions after La Forge (1932)

The relief of the surface is high, ranging from over 350 feet above sea level, at points in the northern highlands, to over 200 feet below sea level in South Boston. The drainage pattern developed on this surface was more well-defined than that of the present, and differed from it in several details. A stream followed the course of what is now the Charles River, from Newton Lower Falls to a point near Allston. Here it joined a large stream flowing into the basin from the north, down the valley now occupied by the Mystic Lakes, across the Fresh Pond section, and on to Allston. From this place the channel crossed the Fens area of the Back Bay, skirted the south side of South Bay, and passed into what is now Boston Harbor. Between Deer Island and Long Island this river was joined by the progenitor of the modern Malden River, which flowed from Wakefield through Mel-

[5] Crosby, W. O., 1903, pp. 251-354 and map facing p. 350; Crosby, I. B., 1923, map facing p. 424; 1927*a*; 1939.

rose, Malden, and Everett, across East Boston, and beneath the present site of Logan International Airport. Bedrock highs existed in the interfluvial areas, and today are marked in many places by superimposed drumlins and more rarely by actual surface outcroppings. This relation between bedrock highs and drumlins is well illustrated by I. B. Crosby.[6]

To what extent this bedrock surface owes its relief to erosion in Tertiary time, and to what extent this Tertiary surface was modified by successive glacial invasions during the Pleistocene, it is impossible to say. It is probable, however, that each ice advance of the Pleistocene effected a considerable amount of modification by ice scour. Also, stream erosion may have occurred during various interglacial periods. The bedrock surface is thus not due entirely to Tertiary stream action, or to Pleistocene ice invasion.

PLEISTOCENE STRATIGRAPHY

General Statement

During the Pleistocene, successive advances and retreats of glacial ice, marked variations in sea level, and strong fluctuations of climate, all served to mantle the bedrock surface with unconsolidated and partly consolidated sediments. It is to these events of the Pleistocene that Boston and vicinity owe much of their present landscape, except in so far as it has been modified by man. It is within the deposits which record the most recent of these events that the Fishweir is buried. The following section of this report discusses in detail the till, glacial clay, glacial sand and gravel outwash, marine silt, and fresh and salt water peat which comprise the bulk of the Pleistocene sediments. With the possible exception of the till described immediately below, all deposits are considered to be Wisconsin in age. They are treated in chronologic order from oldest to youngest.

Pre-Boston Till

Two isolated occurrences are known of till which antedates the till of the Boston substage.[7] Both occur as inclusions within the deposits of the Boston substage.

One such inclusion has been reported from Peddocks Island, a drumlin in Boston Harbor.[8] It is described as a lithified till with a high calcium car-

[6] Crosby, I. B., 1934.

[7] The Boston formation is defined and described on p. 14 and ff.

[8] Crosby and Ballard, 1894, pp. 493-494.

bonate content presumed to have been derived largely from broken and ground up marine shells. Some of this shelly material was still preserved within the inclusion in recognizable fragments. On the basis of their presence the authors suggest that the till was in part derived from the erosion by ice of marine deposits laid down in waters slightly warmer than those of the present.

A second pre-Boston till inclusion was discovered in the clay exposed in the excavation for the foundation of the New England Telephone and Telegraph Company building at Franklin and Congress Streets, Boston (Fig. 5). Due to the interest and cooperation of Mr. G. M. Reaves, project manager for the Turner Construction Company, it was possible to see the inclusion *in situ* and to obtain samples.

The inclusion was very light purplish gray to almost white in color. It was relatively compact, particularly on drying. The matrix was extremely fine-grained, much more so than that of the blue Boston till which is itself relatively high in clay-size components. This fine matrix imparted to the included hard-surfaced stones and cobbles a luster reminiscent of wind polish. The coarse component included chiefly fragments of Cambridge slate, but also a few pieces of granite, volcanic rock and quartzite. The fragments of slate and quartzite were angular. In some instances the igneous rocks had been fractured in a manner suggesting the "snubbing" action arising during glacial transport. The igneous rocks were for the most part unweathered, but the slate and the quartzite were almost without exception bleached to a light gray, matching closely the tone of the till matrix. The freshness of the granite and the volcanic rocks indicated that the inclusion of till was, as a whole, unweathered, and that the slate and quartzite had been weathered before being picked up by the ice.

The pre-Boston till in the Telephone building excavation was undoubtedly ice-rafted and dropped at that point to be buried in glacial clay. The pre-Boston till at Peddocks Island was worked into the drumlin by direct action of the ice. Both are considered older than the Boston substage. The inclusion at Peddocks Island was so lithified as to allow preservation of striae imposed on its surface during Boston time.

The pre-Boston till found in the Telephone building excavation differed considerably in lithologic character from the Boston till. The difference probably stemmed from differences in the surface and near surface zones of the Cambridge slate prior to their erosion by the respective ice advances. Unweathered Cambridge slate is dark blue-gray in color. The weathering on modern outcroppings of the slate is a slight "bleaching" to a light blue or, locally, purplish color. The matrix of the Boston till is predominantly finely-ground, unweathered Cambridge slate and thus has the dark blue-gray

color of the slate. On the other hand the color of the pre-Boston till matrix is purplish gray to white in color. Because the till was unweathered subsequent to its formation this color is thought to be the result of glacial grinding of deeply weathered Cambridge slate.

It is impossible to say whether the two isolated occurrences of pre-Boston till were deposited by the same ice. Both, however, appear as indubitable evidence of at least one ice sheet prior to Boston time.

The Boston Substage

The name "Boston" is here proposed to designate the glacial substage of the Wisconsin which includes the till, clay, sand and gravel described below. The need for a name to designate these units is justified by the extensive development of these genetically related deposits in the Boston area. Because the relation of these deposits to the well-established glacial sequences elsewhere in North America is as yet imperfectly known it is impossible to apply the long-accepted names there used. There are numerous good exposures of the deposits in the Boston area and they are not difficult to distinguish from the other glacially derived sediments of the region. Therefore, their designation as the Boston Substage seems fitting. It is suggested that this name be used until such time as the glacial sequence of New England is well enough defined to warrant the introduction of more general nomenclature.

No specific exposures are designated as type localities because it is felt that the temporary nature of the artificial exposures that have been studied invalidates such a procedure. However, detailed descriptions of the materials representing this substage are given. Future artificial exposures in drumlins and future deep excavations will provide new points of observation which should serve as reference localities for any needed re-examination. Furthermore there are a few natural exposures in wave-cut cliffs on the islands and promontories of Boston Harbor.

TILL

The first Pleistocene deposit of any areal importance in the Boston region is the till member of the Boston Substage. It is most strikingly developed in the nearly 200 drumlins found throughout the Lowland. These drumlins form distinctive hills on the mainland and islands in the harbor. The till also forms a ground moraine which is rarely exposed, being buried beneath glacial clays, outwash, and marine silts. The surface of the till has been mapped in part by W. O. Crosby and by I. B. Crosby.[8]

[8] Crosby, W. O., 1903, map facing p. 359; Crosby, I. B., 1927*b*.

The till varies in thickness from a few feet to probably well over 100 feet. In general, the thicker deposits are in the drumlins, the thinner, in the ground moraine, although this is not always the case. Unweathered till has a characteristic blue-gray color. Weathered till has an over-all rusty, buff color. The till is extremely compact and difficult to excavate, the weathered till being more compact than the unweathered, and dry till more compact than moist till.

The till is essentially unstratified, although some bedded sands and gravel of local extent have been observed in the Governors Island drumlin. Rominger[9] reports a rudimentary orientation of the pebbles and stones in the till of this same drumlin. Two suites of 50 pebbles and stones each were analyzed. One set was found to coincide in general with the long axis of the drumlin, the other was oriented at a normal to this axis. Grade sizes in the till run from colloid size (less than 0.001 mm) to boulders several feet in diameter. Moss has analyzed mechanically several samples of the drumlin till. He found that the till contains from 11 per cent. to 19 per cent. of sizes less than 0.0039 millimeters in diameter and that this aided in distinguishing this till from later till. X ray analysis shows the till matrix below sand size to be chiefly quartz, mica and feldspar. No true clay minerals have been identified. The coarse fraction is composed in large part of rock fragments.[10]

In certain of the drumlins, sea shells and a considerable amount of comminuted shell is found in the till. The shells were first noted as early as the American Revolution in Telegraph Hill, Hull.[11] Numerous discussions of this feature have appeared in the intervening years, but W. O. Crosby and Ballard give the most comprehensive discussion and list a total of 55 different species from various localities in the till. They arrive at the conclusion originally advanced by Desor that the ice which desposited the till scraped up the shells and also mud deposited in waters slightly warmer than the present. Their distribution map shows that the shell is found "in the central and southern portions of the Basin, and overlapping its southern but not its northern margin". Such occurrence is to be expected if the Boston ice had deployed onto an area underlain by marine deposits having somewhat the same distribution as the harbor deposits of the present day.[12]

In its weathered zone the till is cubically jointed, the intensity of such jointing increasing toward the surface. Joint blocks are commonly two to four inches square. Jointing has been observed below the general level

[9] Rominger, 1947. [10] Moss, 1947. [11] Geographical Gazeteer, 1785, p. 56.
[12] Crosby and Ballard, 1894, p. 491, p. 488, p. 489; Desor, 1847.

of the stained and weathered zone to a depth of at least 55 feet beneath the surface.

Because the ground moraine in the Boston Basin was in most places buried by a glacial clay almost immediately after deposition, weathering is restricted largely to the drumlins, the topographic highs. This weathering is expressed in several ways. The rusty, buff color, characteristic of the weathered zone, extends downward for distances of 55 feet or more, the average being approximately 25 to 30 feet. The depth of this zone is greatest under topographic highs. The color is due undoubtedly to an iron oxide. Probably much of this was introduced from above by ground waters bearing it in solution. In the drumlin till, shell fragments are rarely found above the contact of the weathered zone with the unweathered zone and, where present, are partly dissolved or converted into concretionary masses. These concretionary masses are most frequent just above the contact of the weathered and unweathered zones. The shells within this unstained till are relatively unaffected by solution.

In addition to the oxidation and alteration of the till detailed above, a leaching of the iron stain has occurred in the upper five to eight feet. This leaching may be best seen along the joints in the till to depths of $\frac{1}{8}$ inch from the joint planes. Here the color has changed from rusty buff to light, rather bright blue. A thin film of iron and manganese oxides is observable along many of these joints and follows the joints below the leached zone. Above the zone of leaching a congeliturbate[13] two to three feet thick is present. This includes a lower section of frost-disturbed till and a contorted upper loessic zone of fine, yellowish wind-transported material containing ventifacts. Similar aeolian material has been described by Smith and Fraser.[14] A modern gray-brown soil, a few inches in thickness has developed at the surface.

The zone of leaching and the overlying congeliturbate conform with a layer averaging 7.4 feet in thickness reported in a seismic survey of Governors Island[15] and checked by field observations during subsequent excavations on the island. Seismic velocities for this zone average 5717 feet per second for the velocities in the till immediately below. An idealized section illustrating the zonation in the till is presented in Figure 3.

A great majority of the drumlins are known to rest on bedrock highs or have a core of bedrock.[16] The ground moraine equivalent of the drumlin

[13] The term "congeliturbate" has been advanced by Bryan (1947) for the material which has been contorted or stirred up by alternate freezing and thawing. It is compounded from the L. *congelare* to freeze + *turbare* to stir up.

[14] Smith and Fraser, 1935. [15] Lee, 1942.

[16] Crosby, W. O., 1903, p. 359; Crosby, I. B., 1934.

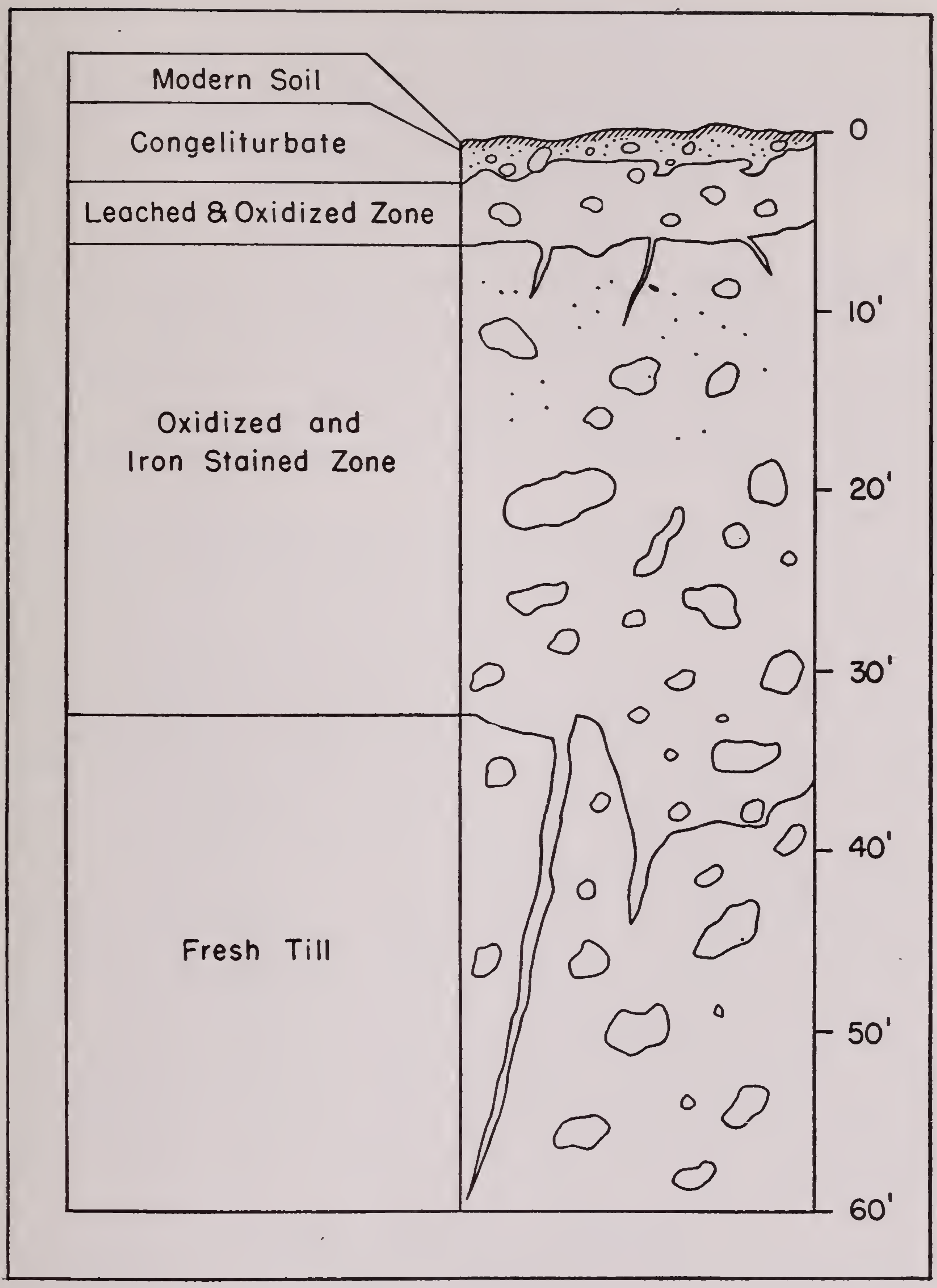


FIG. 3. Generalized Section to Illustrate the Zonation of the Boston Till.

till, however, may rest directly upon bedrock, or may be separated from it by a few feet of stratified sand, gravel or clay. The till, where not exposed at the surface, is, in most places, covered by a glacial clay. The stratigraphic relation of the till to deposits both above and below it is shown in Figure 4, a cross section drawn from Fort Point Hill through Beacon Hill and along the route of the subway to Harvard Square, Cambridge.

CLAY

The clay member of the Boston Substage is widely distributed beneath the City of Boston and underlies, at varying depths, most of the low-lying sections of the city. It is stratigraphically higher than the Boston till and directly overlies it in many localities. The clay is here considered the equivalent of similar deposits throughout the environs of Boston. This assumption is believed valid; the reasons for this belief will be set forth in a later paragraph.

The Boston clay is usually referred to as the Boston blue clay. Actually this clay is more nearly drab, olive green in color. The upper few feet are yellow to buff, in color somewhat similar to the stained zone in the Boston till.

The thickness of the clay is defined by irregular surfaces both above and below. The maximum thickness may reach 100 feet, from which extreme it varies down to a feather edge. The clay is relatively compact, more so in the weathered upper few feet than in the unweathered zone below. Moist clay is in all cases less consolidated than dry clay. The upper few feet have a closely spaced joint system in which the distance between joint planes averages approximately one half inch.

Throughout most of its thickness the clay is soft and plastic. It is less plastic in the weathered zone, and the plasticity of both weathered and unweathered zones is locally reduced by partings of fine sand, or by sand lenses. The amount of sand increases with depth. In some places the clay grades downward into a well stratified sand which becomes coarser with depth and finally grades into a gravel. Scattered through the clay are few pebbles, cobbles and boulders, the largest of the last weighing several tons. The thin irregular beds are generally horizontal in attitude but may exhibit locally aberrant dips.

Table I lists data from mechanical analyses of clay samples obtained from a boring at the John Hancock site. Sample No. One lies near the top of the clay and sample No. Six lies just above the contact of the clay with the till. Sample No. Seven lies in the till just below its top. The table shows that the samples have a median diameter ranging between 0.0012 and 0.0125

Table I. Mechanical Analyses of Boston Clay from the Site of the John Hancock Life Insurance Company

SIZE FRACTIONS

Based on Percentage of Total Weight

	Depth Boston Base	Gravel 30–1 mm	Sand 1–.05 mm	Silt .05–.005 mm	Clay .005–.001 mm	Colloid .001–0 mm
1	−28′	0	1	30	39	40
2	−31′11″	0	1	29	23	47
3	−34′6″	0	10	30	21	39
4	−52′10″	0	11	34	22	33
5	−73′3″	0	18	27	23	32
6	−98′3″	0	33	30	12	25
7	−105′	0	15	25	26	34

STATISTICAL CONSTANTS

	Depth Boston Base	Q_1 mm	M mm	Q_3 mm	So
1	−28′	.0054	.0018	.00053	3.19
2	−31′11″	.0066	.0012	—†	—
3	−34′6″	.0105	.0022	.00065	4.02
4	−52′10″	.028	.0038	.00048	7.64
5	−73′3″	.0158	.0023	.00056	5.31
6	−98′3″	.11	.0125	.001	10.49
7	−105′	.0125	.0026	—*	—

† Q_3 not reached after 74 hours of settling.
* Q_3 not reached after 96 hours of settling.

millimeters. The average for the six samples of clay above the till is 0.004 millimeters. The sorting coefficient, varying between 3.19 and 10.49, is characteristic of the poor sorting expected in a clay. In general, the total percentages of particles of clay and colloid sizes decreases with depth, and the sand and silt fractions increase.

Thin sections of clay from Boston, Cambridge, Saugus and Lynn show a sprinkling of phenoclasts in a groundmass having an index of refraction less than 1.54. The phenoclasts in the sections examined were essentially similar. They comprise 10 to 30 per cent of the whole. Quartz, plagioclase feldspar, microcline, muscovite, green biotite, garnet, zircon, magnetite, sphene and hornblende were all identified. In those sections of samples from the John Hancock site the coarsest phenoclasts occur toward the base of clay, just above the till; here many are minute rock fragments.

In an attempt to determine the mineral composition of the finer components of the clay an X ray analysis of samples from Boston, Cambridge, Saugus and Lynn was made. Quartz, muscovite, and feldspar, including plagioclase probably in the oligoclase-labradorite range, and probably orthoclase, were identified. Some unassignable patterns appeared. No variation in pattern was noted from locality to locality. No hydrous aluminum silicate minerals, i.e. "true clay" minerals, were identified. It will be noted that this mineral content corresponds to that of the till matrix as determined by Moss.

No macro-fossils have been found by the writer in the Boston clay. However, Nichols and Sears have collected invertebrates from the clays at Lynn which indicate the deposition of the clay in cold water.[17] Local residents report a single occurrence of a fish from the same area, but this find, along with the reported discovery by workmen of shell material in the North Cambridge clay pits, is unsubstantiated. The foraminifera, diatoms, and pollen from the Boston clay are described elsewhere in this volume by Phleger, Conger, and Wilson, respectively.

During the mechanical analysis of the clay from the John Hancock excavation a very minute quantity of what is presumed to be organic matter was separated but it could not be identified.

As noted above, the upper part of the Boston clay is weathered. This zone is in most places yellow, but elsewhere it is the same bright blue that occurs along the leached joints of the upper part of the Boston till. The blue color appears to be the result of leaching, either along the joints in the clay, or in a distinct zone above the yellow clay or irregularly distributed

[17] Nichols, 1946; Sears, 1905.

through the yellow clay giving it a mottled appearance. This weathered zone is described by drillers by the adjectives "hard", "stiff", or "medium", "yellow" or "blue clay". The zone is two to ten feet thick in most places, but borings have recorded up to 30 feet of weathering.

Thin sections of clay from Boston, Cambridge, Saugus, and Lynn show a startling difference in structure between the weathered and unweathered zones. The platy minerals of the groundmass of the unweathered clay are oriented roughly parallel to the bedding. In contrast, the groundmass of the weathered clay is broken into angular, irregular blotches ranging from one to eight millimeters in maximum dimension, and averaging three to four millimeters. Within each individual blotch, the platy minerals are arranged in a subparallel manner, but their orientation is completely different from the minerals of adjoining blotches. They may be cut or separated from neighboring blotches by thin veinlets whose minerals have optical orientation different from that of the minerals of the blotches.

Samples from the John Hancock excavation and the excavation for the New England Telephone and Telegraph Company building, at Congress and Franklin Streets, Boston, show that minute dislocations occur in the blotches along planes of displacement. The pattern of this micro-faulting is that of "normal" faults. Veinlets of platy minerals are oriented between faulted units parallel to the fault planes. The weathered clay from the North Cambridge clay pit shows a suggestion of shearing but no normal faulting. There is no evidence for either shearing or normal faulting in the Lynn and Saugus clay.

No differences of mineral content between the weathered and unweathered clay were detected in X ray analysis, nor was any difference noted between the blue and yellow clays within the weathered zone.

The upper surface of the Boston clay is eroded as well as weathered. The compilation of boring records from Boston and vicinity has permitted a reconstruction of this surface. This contour map on the surface of the clay is reproduced. (Fig. 1*a*.)[18]

An examination of the map shows a well-developed stream pattern. The major drainage followed approximately the course of the modern Charles

[18] The map is based largely on drill records on file in the Library of the Boston Society of Civil Engineers, 88 Tremont Street, Boston. Approximately 3000 logs were used in the construction of the map. A portion of these records have been published (Boston Society of Civil Engineers, 1931). Additional information has been obtained from the excavations for building foundations for the New England Mutual Life Insurance Company, the John Hancock Life Insurance Company and the New England Telephone and Telegraph Company, and from records kept during the construction of the Boylston Street Subway. The datum used is Boston City Base.

River, into the inner harbor and thence to the outer harbor. A second major channel enters from the north between Charlestown and East Boston. Still a third stream lies beneath what is now Fort Point Channel. The surface was continuous with the till highs. It will be noted that a small tributary to

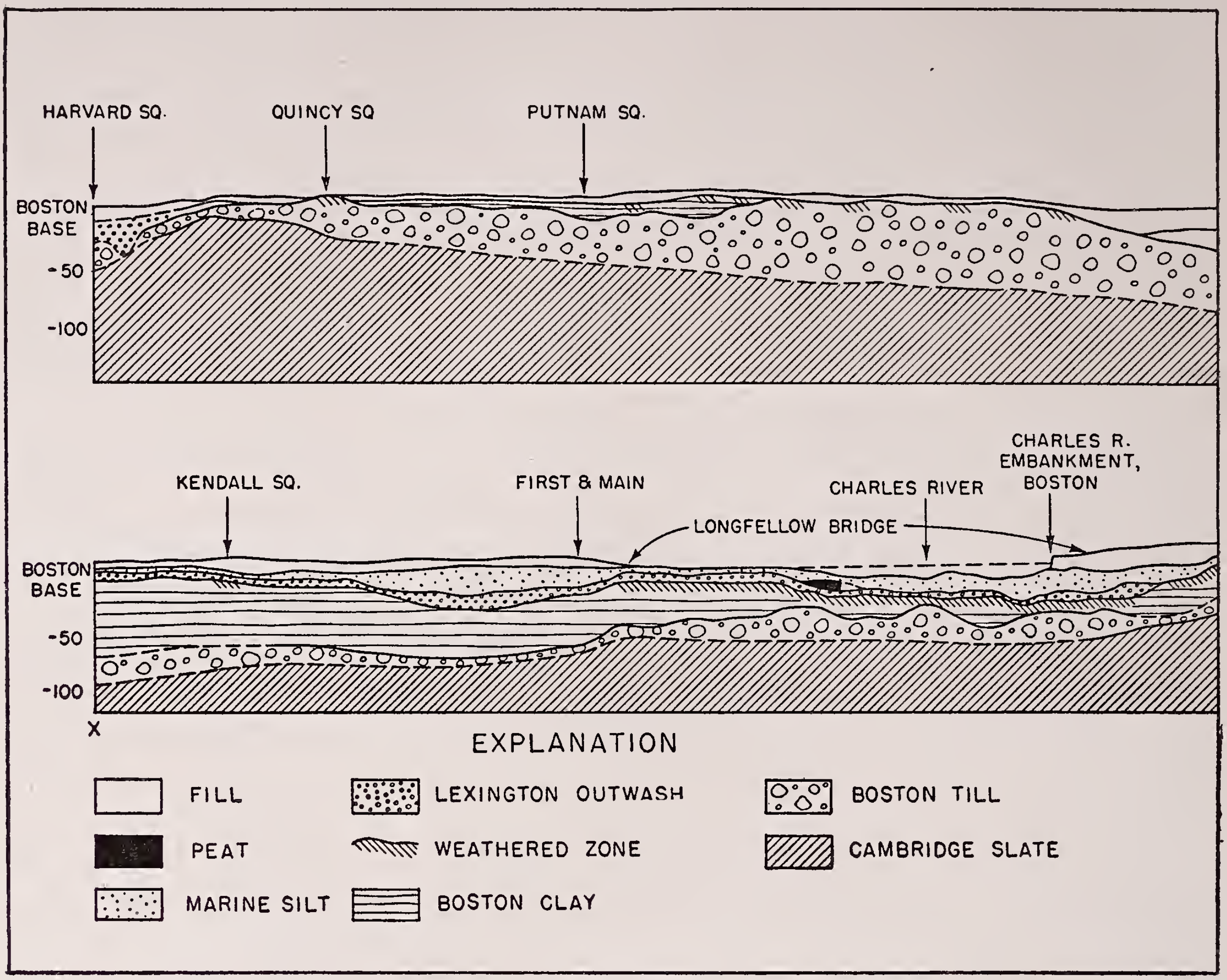
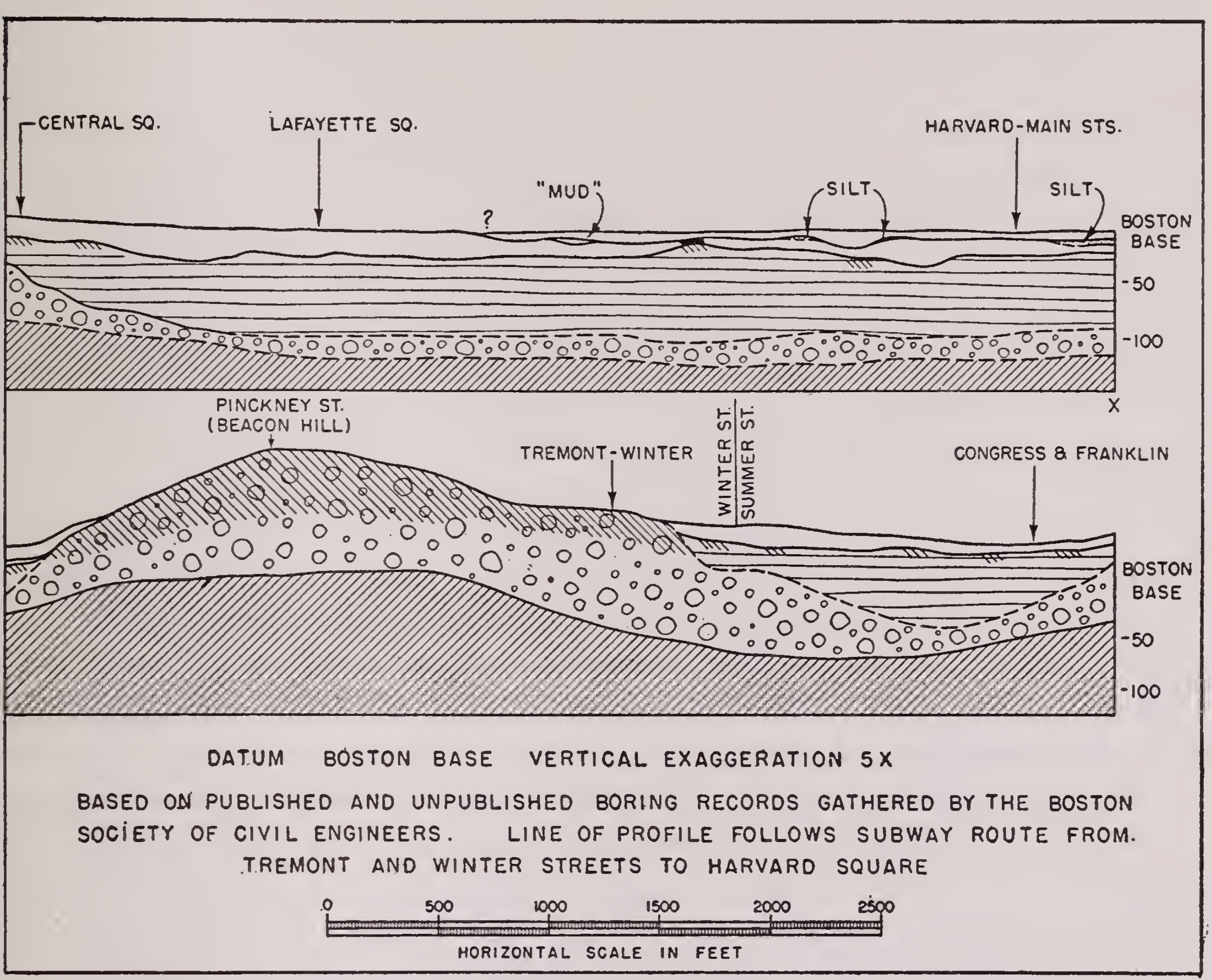


FIG. 4. Geologic Section from Fort Point Hill, Boston, to Harvard Square, Cambridge. Based on Boring Records on File in the Library of the Boston Society of Civil Engineers.

the old Charles drained the area later to be occupied by the Fishweir. This stream flowed in a general northwesterly direction from the east end of Boston Neck, and then turned northeast along what is now Fairfield Street until it joined with the ancestral Charles. Boston Neck, the low isthmus which connected colonial Boston with the mainland to the west and which corresponded to the present position of Washington Street, was extant at this time as a topographic high. Weathering of the clay is present over the entire clay surface but is deepest along its higher points.

An attempt to determine the base level to which the streams on this surface were graded appears in Figure 1*b*. Known points along the old Charles were plotted from the contour map. Others were determined from sections upstream in Brookline, Cambridge and Brighton. The fragmentary



profile thus obtained has been projected beneath the modern Charles River channel and Boston Harbor until it intersects the present ocean floor. With allowance for a decrease in gradient down stream, the projected profile indicates that the sea level to which this stream was graded stood between 90 and 100 feet below the present sea level. The errors inherent in such a procedure are fully recognized. Nevertheless, the figure thus obtained is felt to be of the correct order of magnitude.

Although the drainage of the mapped surface is perfect, closed depressions do exist on the surface outside of the area contoured. These are considered to be ice block holes. The most extensive depression discovered

during the examination of boring records is located along the Charles River. It extends from approximately 1000 feet downstream from the Cottage Farm Bridge up stream almost to the River Street Bridge. Its total area was not definitely determined, but it underlies part of both Cambridge and Boston. I. B. Crosby cites figures which suggest additional undrained depressions on this surface.[19]

In most instances where the nature of the basal contact is known, the clay rests on unweathered Boston till, or grades into a gravel which in turn rests on the same till. An excellent opportunity to see this relationship was provided in the excavation for the foundation of the New England Telephone and Telegraph building in January, 1947. The exposure showed ten feet of fill overlying the weathered surface of the Boston clay (Fig. 5). The clay varied in thickness between 24 feet and 32 feet, the upper ten feet of which were weathered to a yellow color. The clay graded rather abruptly into a fine, water-laid sand one to seven feet in thickness. This in turn overlay a bed of boulders and fine sand, two to three feet in thickness. Beneath this lay the fresh and unaltered Boston till.

The clay occupies the topographic lows between till highs, leaving the drumlins as islands surrounded by a sea of clay. The clay reaches to approximately 30 feet above sea level in Boston and extends in places to nearly 200 feet below sea level. It is disconformably overlain by deposits of a later glacial advance, by peat and by marine silts. The stratigraphic position of the clay may be seen in Figures 4, 5, and 9.

On the basis of the evidence detailed above, combined with the reports on diatoms, foraminifera and pollen by Conger, Phleger and Wilson, it is obvious that the Boston clay is of glacial origin and was deposited in marine or brackish waters when sea level stood more than 30 feet higher than at the present. The clay is genetically related to the ice which plastered the Boston till over the bedrock floor of Boston Basin. Its deposition followed closely on the retreat of the ice, but it is separated from the till in some places by a sand and gravel outwash. The clay represents the fines carried by proglacial streams from the melting and retreating ice at a time when it stood some distance north of Boston. Subsequently, it was exposed to subaerial weathering and erosion when sea level stood between 90 and 100 feet below that of the present.

Throughout the above discussion of the Boston clay it has been assumed that the clays in the City of Boston are equivalent to clays found elsewhere in the Boston Lowland. It is possible to trace by drill records the clay which

[19] Crosby, I. B., 1934.

lies beneath Boston as far as Harvard Square, Cambridge. It has not been possible to connect this clay with that found in North Cambridge, Belmont and Arlington or with the clays to the north of Boston which extend as far as Lynn. Nevertheless, the similar lithology, the altitudes of top and bottom,

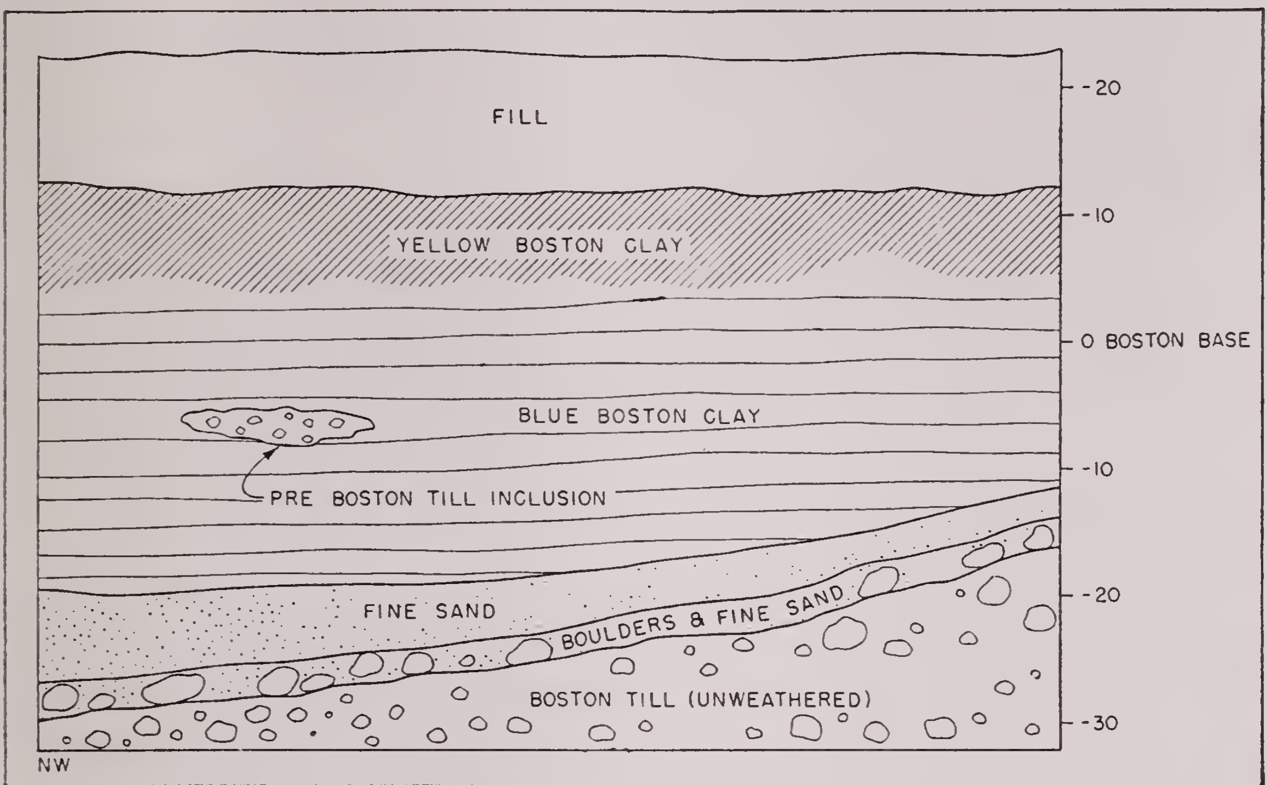


FIG. 5. Geologic Section to Illustrate the Relation between Boston Clay and Till at the Site of the New England Telephone and Telegraph Company Building, Franklin and Congress Streets, Boston.

the degree and type of weathering, and the stratigraphic relations with deposits both above and below all point to a common age and origin.

The Lexington Substage

The name "Lexington" is here proposed to designate the glacial substage of the Wisconsin which includes the till, sand and gravel to be described below. It is proposed for the same reasons as was the name "Boston Substage" above, and because the deposits are well exposed at various places in the vicinity of the town of Lexington, Mass. It is again suggested that the name be considered as a temporary expedient until some more fitting name is available. As in the case of the Boston Substage, no specific exposures are cited as type localities.

TILL

The till of the Lexington Substage is distributed over large sections of the western part of the Boston Basin and along its northern rim. The Lexington ice did not cover the northern and eastern portions of the basin. It advanced to the northeastern edge. To the west, it sent a tongue down the valley now containing the Mystic Lakes, reaching a line now marked by the Fresh Pond moraine, in Cambridge. It covered the greater part of Brookline, and all of the Newtons, and its border swung southeasterly through the southern part of the basin.

In most exposures the till is thin, averaging 15 feet in thickness. In some places, 30-foot cuts have failed to expose its lower limit. Unweathered till is light gray in color. It has a slight rusty staining at its upper limit. It is unconsolidated, and in vertical or high angle exposure faces, is subject to slump. The till is very porous and, compared to the Boston till, very low in clay and colloid sizes.[20] Boulders up to ten feet in maximum dimension are common. In general, it contains more of these large boulders than does the older, Boston till.

The weathered zone reaches two to three feet in depth and is characterized by a limonitic stain which grades downward into the gray unweathered till. This zone is overlain in most exposures by a frost-disturbed till zone, and by blown sand or silt containing ventifacts. The thin, modern soil is developed over this congeliturbate. Where the base is exposed, it is seen to rest either on the bedrock surface or on the Boston till or equivalent outwash. The contact of these two tills is not sharp in most instances, a mixing having been effected. The Fresh Pond moraine is considered to be a push moraine formed by Lexington ice. It overlies distorted beds of Boston clay. The till in the moraine is not typical Lexington till, because a large part of the material which comprises it was derived from the inclusion in it of the Boston clay of Arlington, Belmont and North Cambridge.

As noted previously, the Lexington ice did not cover the eastern portion of the Boston Basin. The ice front along the northern edge of the Basin is not to be considered a southward, but, rather, an eastward limit of the ice. It undoubtedly spread southward, investing much of southern New England with a till mantle similar to the true Lexington till already described.

SAND AND GRAVEL OUTWASH

A glacial outwash of the Lexington substage is widely distributed in the Boston area. The outwash is confined to the lower portion of the

[20] Moss, 1943; 1947.

Lowland lying between the drumlins. Boring records show that it is not well developed east of the Back Bay section of Boston. To the north, west and south of this area it thickens and crops out in road cuts and excavations.

Thickness of the outwash ranges between a few inches to 50 feet or more. Its color is a light, sandy gray, although its upper two to three feet has a slight rusty color. The outwash is unconsolidated, well-stratified and easily excavated. The coarse fraction is composed of rounded to subangular pebbles and small cobbles representing rock types from the Boston Basin and surrounding highlands. The grade sizes include very little fine material and a large percentage of coarse sand and gravel.

Weathering is confined to the upper two to three feet and consists of a limonite stain decreasing in intensity from the surface downward. As in the case of other surface exposures of the area, a zone of blown sand, ventifacts and frost-disturbed material is in many places present just below the thin, gray-brown, modern soil.

The outwash lies disconformably over the eroded and weathered surface of the Boston clay. The writer has observed this relationship in excavations in the Revere and Lynn marshes and it is known to exist along the southern portion of Oxford Street, Cambridge. The relationship is recorded in boring records throughout the Boston area and is shown in the profile (Fig. 4).

The outwash lies disconformably over the eroded and weathered surface of the Boston clay. In some places, the drainage system previously developed on the surface of the Boston clay was disrupted by the influx of this younger glacial outwash. Of particular importance to this study is the blocking of the stream draining the area later occupied by the Fishweir. Accumulations of Lexington outwash along the lower part of this stream in the vicinity of Fairfield Street created a poorly drained depression upstream. This feature will be referred to in later sections. The outwash is exposed at the surface at many places. Elsewhere, boring records show it to be overlain by peats and marine silts. Figure 4 illustrates these stratigraphic relations.

The eroded and weathered surface of the Boston clay over which this outwash lies indicates a considerable time intervening between the two glaciations. As stated above, the Lexington ice failed to cover a large portion of the Boston Lowland. This fact, plus the deposition of the Lexington outwash and later sediments in this area explains the preservation of the topography developed on the Boston clay.

The sea level during and immediately following deposition of the Lexington outwash was in all probability higher than the present. Hörner

describes a raised beach on the south side of Baker Hill, Saugus.[21] Its map elevation is between 40 and 50 feet. Correlative with this are the levels of numerous valleys entering into the basin from the north. They are choked with outwash graded to a level between 40 and 50 feet above the present sea level.

CONGELITURBATE

In the excavation for the John Hancock building a discontinuous layer of congeliturbate lay immediately over the weathered surface of the Boston clay. The geographic extent of this zone outside the excavation is unknown, but drill records suggest that it is not confined to the building site.

The deposit reaches a maximum thickness of three feet and averages 18 inches. The thickest sections were found where the clay surface had its least altitude. Color of the deposit is the bright blue described from the weathered zone of the Boston till and clay. The zone is well-packed but essentially unconsolidated. It is not as hard as the clay immediately below.

Although the grade sizes range from colloid to cobble, the deposit is zoned in a rudimentary way. Gravel tends to be concentrated as lenses at the base of the zone. Above this is a clayey sand with admixed pebbles and cobbles, which in turn grades upward into a soft plastic clay with little sand. A mechanical analysis of the clayey sand zone, which forms the bulk of the congeliturbate, shows it to have a median diameter of 0.061 millimeters and a sorting coefficient of 2.39. The size fractions included 57 per cent. sand (1–.05 mm), 30 per cent. silt (.05–.005 mm), 6 per cent. clay (.005–.001 mm) and 7 per cent colloid (.001– 0 mm). Some of the pebbles from both this and the gravel show wind-polished and abraded surfaces. One of these ventifacts is a fragment of Cambridge slate which has been polished and fluted by wind action (Plate I). A microscopic examination of the sand fraction of the congeliturbate revealed no frosted grains thought to be typical of blown sand.

Both the upper and lower contacts of the zone are sharp and well defined. It lies disconformably over the weathered clay, and is in turn covered by a peat or rusty sand to be described in subsequent sections. These relations are shown graphically in the detailed sections at the John Hancock site (Fig. 10).

The deposit is considered to have originated under the rigorous conditions of a periglacial climate. The source of the material comprising

[21] Hörner, 1929, p. 127.

PLATE I

A Fragment of Cambridge Slate from the Congeliturbate at the John Hancock Site to Illustrate Wind Polish and Fluting. Maximum dimension ca. 2.9 inches.

the congeliturbate was probably threefold. The site of the John Hancock building is situated on a slope which rose eastward during Lexington time and later. This topography closely approximated that of the surface of post-Lexington time as shown by the map (Fig. 6) to be discussed in a later paragraph. Material undoubtedly was moved down this slope by the process of congeliturbation. The clay and colloid fractions probably represent a reworking of the Boston clay. This clay also contains scattered pebbles some of which may be represented as a lag gravel in the congeliturbate. It is possible also that gravel may have moved down slope from exposed Boston till to the east. Finally, some of the sand fraction may have been contributed by winds transporting material from deposits of Lexington outwash and till to the west and north. The deposit is thought to be chronologically equivalent in part to the deposition of Lexington till and outwash, and in part to the retreat of the Lexington ice.

The Lower Peat

A buried peat is widely, though discontinuously, distributed over large portions of the Boston area.[22] In all cases it lies below zero of the Boston Base. Between Deer Island and Logan International Airport the peat lies at a depth of –45 feet, Boston Base. I. B. Crosby reports a peat 48 feet below present mean low tide in Roxbury.[23] The thickness of the peat may vary from a thin humic zone to several feet. The color varies between black and brown, the latter probably being more characteristic of the bulk of the deposit. Some silt is commonly mixed with the peat. The lower contact of the peat may be clean-cut, particularly where it rests on clay. Where the underlying beds are sand and gravel, the contact may be somewhat gradational. The upper contact may be either sharp or gradational. In all localities it is overlain by a marine silt.

Both fresh-water and salt-water facies are known from this lower peat. The salt-water peat at any given level marks the approximate position of the shoreline of a rising sea. The fresh-water peat does not bear such a relation even though it may be later covered by a salt-water peat. Thus the lower horizons of the peat beneath both the John Hancock and New England Mutual buildings represent a period of peat formation above sea level on a poorly or partly drained topography. The salt-water facies represents the shore of a sea which subsequently flooded this deposit.

[22] For a detailed description of the peat as found in the John Hancock excavation see Barghoorn, and Wilson, this volume.

[23] Crosby, I. B., 1934, p. 149.

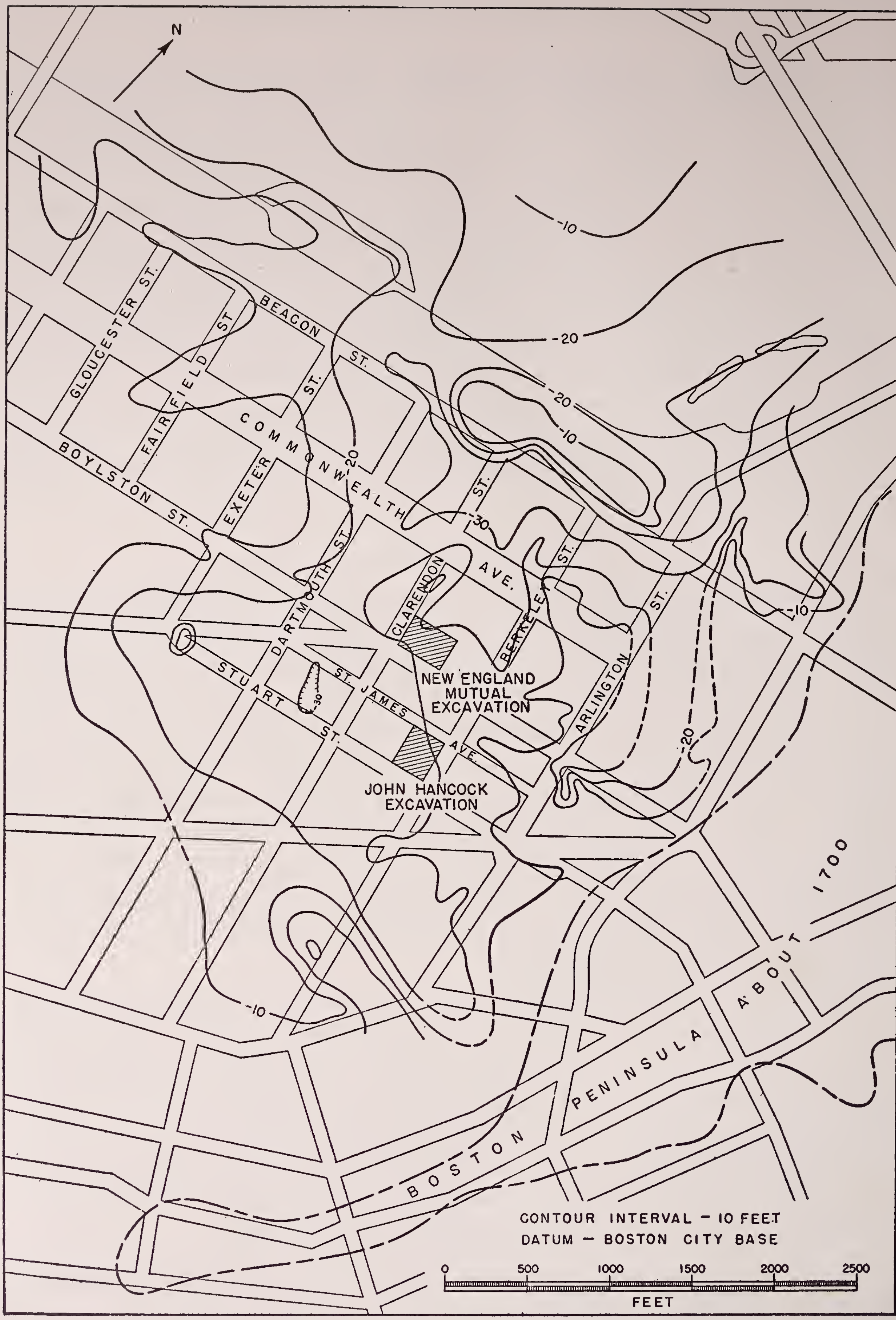


FIG. 6. Contour Map to Show Topography in Back Bay During Post-Lexington Time. Based on Boring Records on File in the Library of the Boston Society of Civil Engineers.

The Silt

A marine silt lies stratigraphically above the lower peat. It is restricted to sections at or below zero, Boston Base, and underlies some of the marshes of the Boston area, as well as the made land, the river estuaries and the harbor. It is known to have a lower limit of at least −49 feet, Boston Base, in the outer harbor and it presumably extends below this. Its thickness probably does not exceed 40 feet, and in most places is between 10 and 25 feet, although it is thinner at several points.

Its color is a light, greenish gray, which becomes lighter in tone with drying. It is horizontally bedded in thin layers which are easily discernible only under certain conditions of moisture content between fresh exposure and complete drying. It is a fine-grained deposit of megascopically uniform consistency, and is unweathered.

Mechanical analyses of the silt from the John Hancock site were made (Table II). This particular suite of samples shows significant variations of the median diameter and sorting coefficient, variations which are in all probability peculiar to their particular environment (Fig. 7). It will be noted that the coarser the median diameter, the better the sorting of the material, i.e., the closer the sorting coefficient to unity. Conversely, with a decrease in the median diameter, the sorting becomes less perfect. Below −13 feet 6 inches, Boston Base, the median is low, the sorting poor. Above this level, the median is in general high and the sorting better. An exception to this is seen in the marked decrease in the median with concurrent poor sorting at −12 feet 7 inches, Boston Base. This is correlated with an oyster bed, two feet in thickness, which apparently functioned to reduce the sorting efficiency of tidal currents. With the burial of the bed, sorting becomes better and median coarser.

The basic cause for the change in the character of the deposit lies in the nature of the topography invaded by the rising sea which laid down the silt. Figure 6, a contour map of the base of the peat, or, where this is missing, of the base of the silt, represents this topography in Boston and the immediate vicinity. From the map, it is apparent that the sub-silt topography in this section of the Back Bay is a poorly-drained shallow depression. As noted previously, this basin was formed by Lexington outwash blocking the lower part of the valley which developed on the surface of the Boston clay and drained this area during a part of the Boston-Lexington interval.

The lowest brim of this basin is to the north, and the lowest point in this northern side is a saddle between the basin and the ancestral Charles, between Clarendon and Dartmouth Streets. An examination of Figure 6

Table II. Mechanical Analyses of the Silt from the Site of the John Hancock Life Insurance Company

SIZE FRACTIONS

Based on Percentage of Total Weight

	Depth Boston Base	Gravel 30–1 mm	Sand 1–.05 mm	Silt .05–.005 mm	Clay .005–.001 mm	Colloid .001–0 mm
1	+1′2″	0	57	40	3	Tr
2	0′	0	41	50	6	3
3	−4′	0	34	44	13	9
4	−11′	0	56	33	6	5
5	−11′3″	0	40	51	5	4
6	−12′7″	0	25	45	11	19
7	−13′	0	57	29	7	7
8	−13′4″	0	30	49	13	8
9	−13′6″	0	17	55	16	12
10	−14′9″	0	15	56	18	11
11	−18′4″	0	13	63	16	8
12	−22′2″	0	5	66	19	10

STATISTICAL CONSTANTS

	Depth Boston Base	Q_1 mm	M mm	Q_3	So
1	+1′2″	.074	.054	.040	1.22
2	0′	.060	.042	.019	1.78
3	−4′	.059	.034	.0088	2.55
4	−11′	.074	.055	.035	1.45
5	−11′3″	.057	.041	.024	1.54
6	−12′7″	.051	.0145	.0029	4.19
7	−13′	.067	.062	.0205	1.81
8	−13′4″	.055	.03	.0088	2.45
9	−13′6″	.039	.0156	.0037	3.23
10	−14′9″	.030	.0122	.0032	3.05
11	−18′4″	.046	.018	.0053	2.95
12	−22′2″	.0325	.0195	.0040	2.85

shows that the seas, flooding the basin from the north, would enter across this saddle. The low median diameter and poor sorting is correlated with this early flooding when tidal currents were unable to work effectively within the basin. As the sea rose, it eventually topped the higher parts of

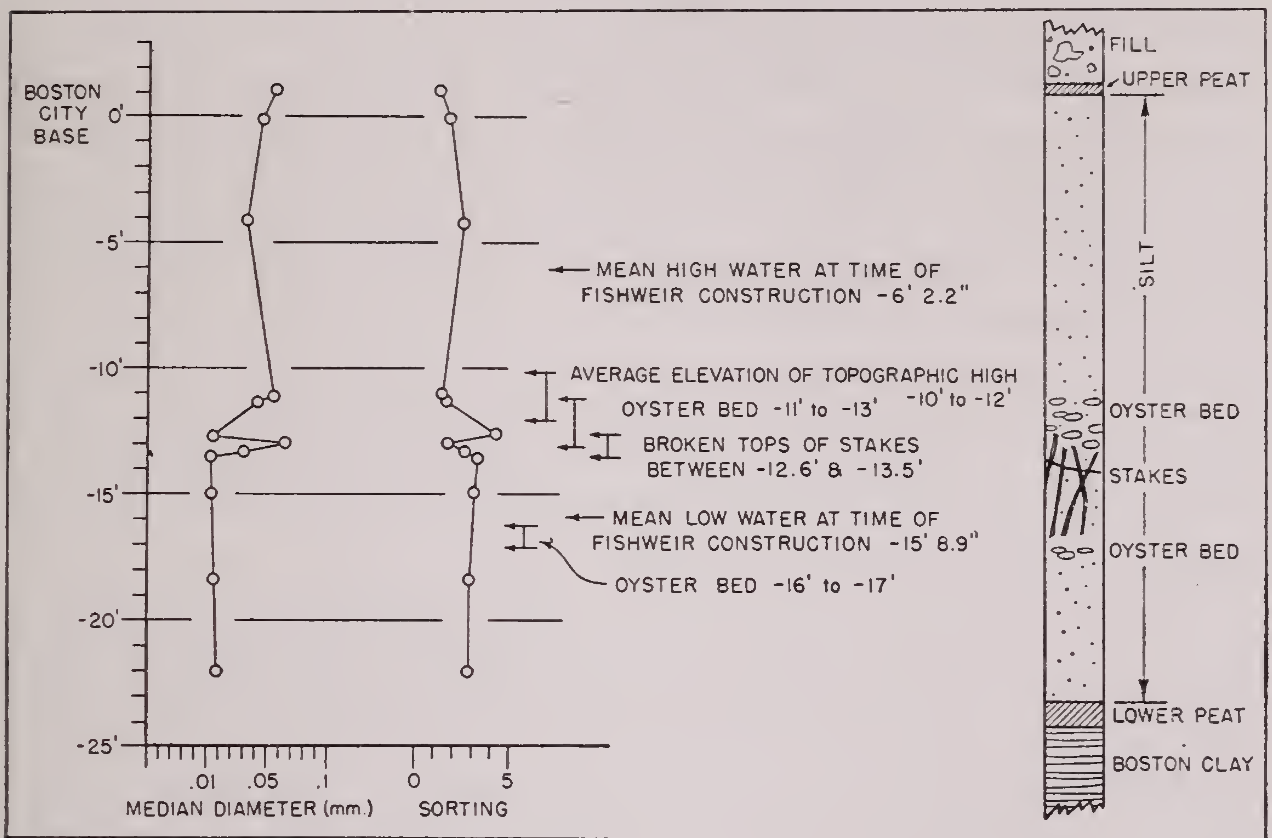


FIG. 7. Diagram to Illustrate the Variation in Median Diameter and Sorting of the Silt at Various Levels in the John Hancock Excavation.

the northern brim which, just north of the John Hancock site, has an average elevation between −10 feet and −12 feet, Boston Base. With the topping of this barrier, the tidal currents became more effective, sorting more perfect, and median coarser. (See Fig. 7.)

Shortly thereafter, the upper oyster bed became an extensive and well-developed horizon, effectively curtailing the sorting efficiency of the tidal currents (Fig. 7). The appearance of this oyster bed at this time can be explained in part by the sub-silt topography and in part by the Fishweir. As pointed out by Nelson [24] "Abrupt changes in the level of the bottom, or ob-

[24] Nelson, 1942, p. 50.

stacles in the tide way which produce eddies and slicks serve as larval traps in which the [oyster] larvae accumulate and beneath which they usually set most heavily on the bottom if surfaces for attachment be available." The northern rim of the basin served as an obstacle to the tidal flooding, although it was topped by all but low tides. It follows that a larval trap should be set up on the lee or basin side of this barrier. The abandoned weir, along with a few already-established oyster clusters, would have served as surfaces of attachment. Physical conditions thus favored the rapid expansion of the oyster bed. Once established, the bed continued to expand basinward outside of the area of the weir. When, however, even the lowest tides overran the topographic high to the north, the oyster bed was soon buried. The sorting of the silt from this time on is more perfect and the median diameter correspondingly coarser.

The studies of the diatoms, foraminifera, and pollen in the silt appear elsewhere in this volume. In addition to the micro-fossils the silt contains many species of larger marine invertebrates such as the oysters discussed above. The total association indicates slightly warmer waters during silt deposition than now prevail at Boston.[25]

The silt overlies the lower peat, or, where the peat is absent, lies on Boston clay, Lexington outwash, or congeliturbate, depending upon their distribution. In many places it is overlain by a peat, termed the Upper Peat which is to be next described (Figs, 4, 9 and 10).

The silt was laid down in a sea transgressing an irregular topography. The faunal and floral evidence to date indicates that conditions were slightly more equable than those which obtain in this area today. The basal portion of the silt is in many places a marine peat. This peat marks the shoreline of the rising sea at any given level.

The Upper Peat

In many places a second peat bed is present. This upper peat is widely distributed in the tidal marshes and beneath the made land. It varies from a thin film to three feet in thickness. Its color is a black to gray brown and it contains, locally, large amounts of silt and sand.

This peat, as in the case of the lower peat, is in places composed of both fresh- and salt-water facies. Again the fresh-water zone, when present, is basal. It is found widely beneath the modern tidal marshes. Stumps of trees have been observed in the Wellington Marsh along the Mystic River, and in the Revere marshes to the north.

[25] Shimer, 1918; Clench, 1942; Nelson, 1942; Lindquist, et al, 1942; also Conger, Wilson and Phleger, this volume.

The upper peat grades downward into silt, or, where the silt is absent, into the Lexington outwash. In places it rests on the Boston clay. It may be covered by man-made land or it may form the surface of the modern salt marshes.

This peat, along with the underlying silt and lower peat, represents an extensive rise of the sea during the immediate geologic past. Whether or not the sea is still rising in relation to the New England coast has been long debated. Johnson's excellent summary of the arguments demonstrated their inconclusive nature at that time.[26] He points out, however, that the nature and structure of the coastal marshes indicates continued subsidence or invasion by the sea. Detailed archaeological and botanical investigations in the Taunton River, Massachusetts, indicate a continuous rise of sea level in that area for the last 600-700 years and continuing to the present.[27] More recently Marmer has analysed tidal records of the Atlantic coast and has established that from 1930 to 1937 the sea rose at a rate of 0.02 feet per year, and that for the preceding 35 years it had been rising at approximately one-seventh this rate.[28] It seems safe to assume that there is a continued, although very slow, rise of the sea in relation to the land in the Boston area.

Figure 8 is an idealized diagram to illustrate the formation of peat and silt in a rising sea and to show their interrelations. When the sea stands at level A-B salt-water peat forms along shore at B. Sea level rises and similar conditions prevail along the new shores. The peat thus formed is in many instances, undoubtedly, destroyed by the advancing sea itself. During this rise of the sea, fresh-water peat may form at favorable localities such as C, C′ and C″. By the time the sea reaches level A′–B′, it has overridden fresh-water peat at C and covered it with a salt-water peat. As the sea continues its rise, salt-water peat again buries fresh-water peat, this time at C′. By the time the sea reaches level A″–B″ transgression slows or stops and a marine peat grows out over the silt previously deposited. Fresh-water peat may continue to form above sea level at C″.

Several conclusions are immediately apparent from such a series of events. The marine peat from B through B″ is more or less continuous, but the peat at B is obviously older than that at B″. No single locality gives a complete record of the time elapsed during the formation of the peat.

Under ideal conditions the fresh-water peat will form until covered by the advancing sea. Thus, where salt-water peat overlies fresh-water peat, the time interval recorded in the two peats is apt to be longer than that recorded

[26] Johnson, et al., 1942, pp. 172-178.
[27] Johnson and Raup, 1947.
[28] Marmer, 1948.

in any one section of salt-water peat. Theoretically, there is no reason why the peat at C″ could not have been forming during the entire advance of the sea. Likewise, it is possible that a section of marine peat which grades down into the fresh-water peat at C′ would represent the entire time from level A-B to the present, or longer. The completeness of such sections will, of course, depend upon local conditions. It must be admitted that a complete record in the peat for the whole of the time elapsed during the rise of the sea will be rare.

The upper salt-water peat may be considered continuous with the lower salt-water peat. It differs from it only in time and geographic position. Although the formation of salt-water peat has kept pace with rising sea, at various places it may be largely destroyed if flooding continues.

Artificial Fill

Throughout Greater Boston are large amounts of made land. The great bulk of this lies above old tidal flats. Most of the filling has been done since the middle of the last century.

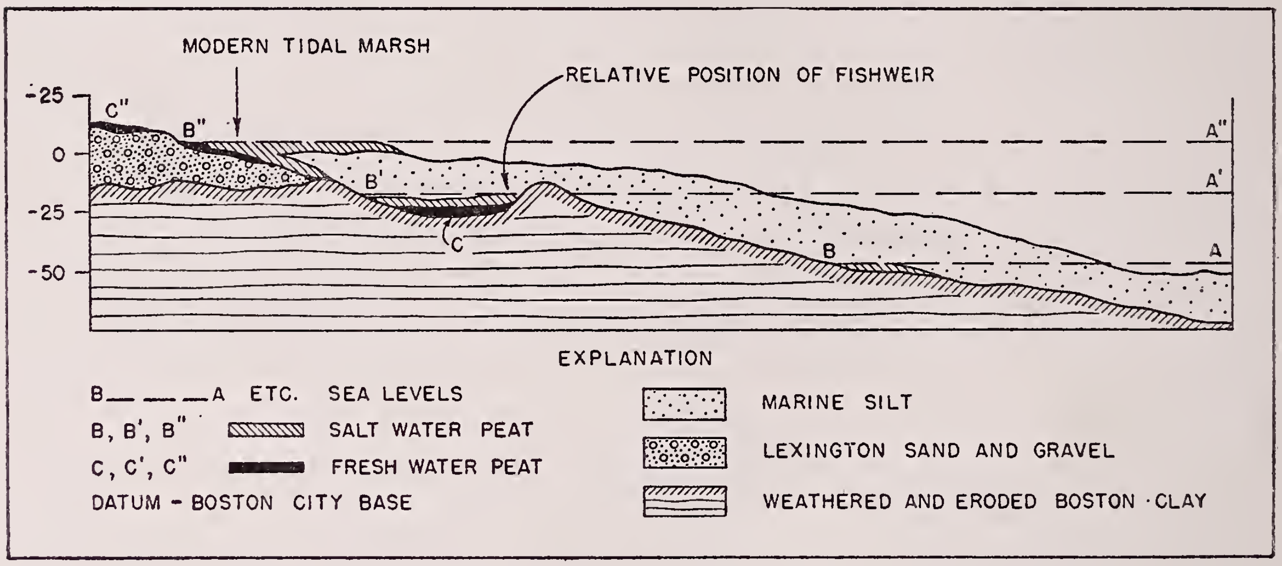


Fig. 8. Diagram to Illustrate the Formation of Peat in a Rising Sea.

THE GEOLOGIC SEQUENCE AT THE JOHN HANCOCK SITE

The geologic sequence at the site is best visualized by reference to Figures 9 and 10. Figure 9 includes generalized cross sections at the site, along selected lines of section. The detailed sections in Figure 10 illustrate the

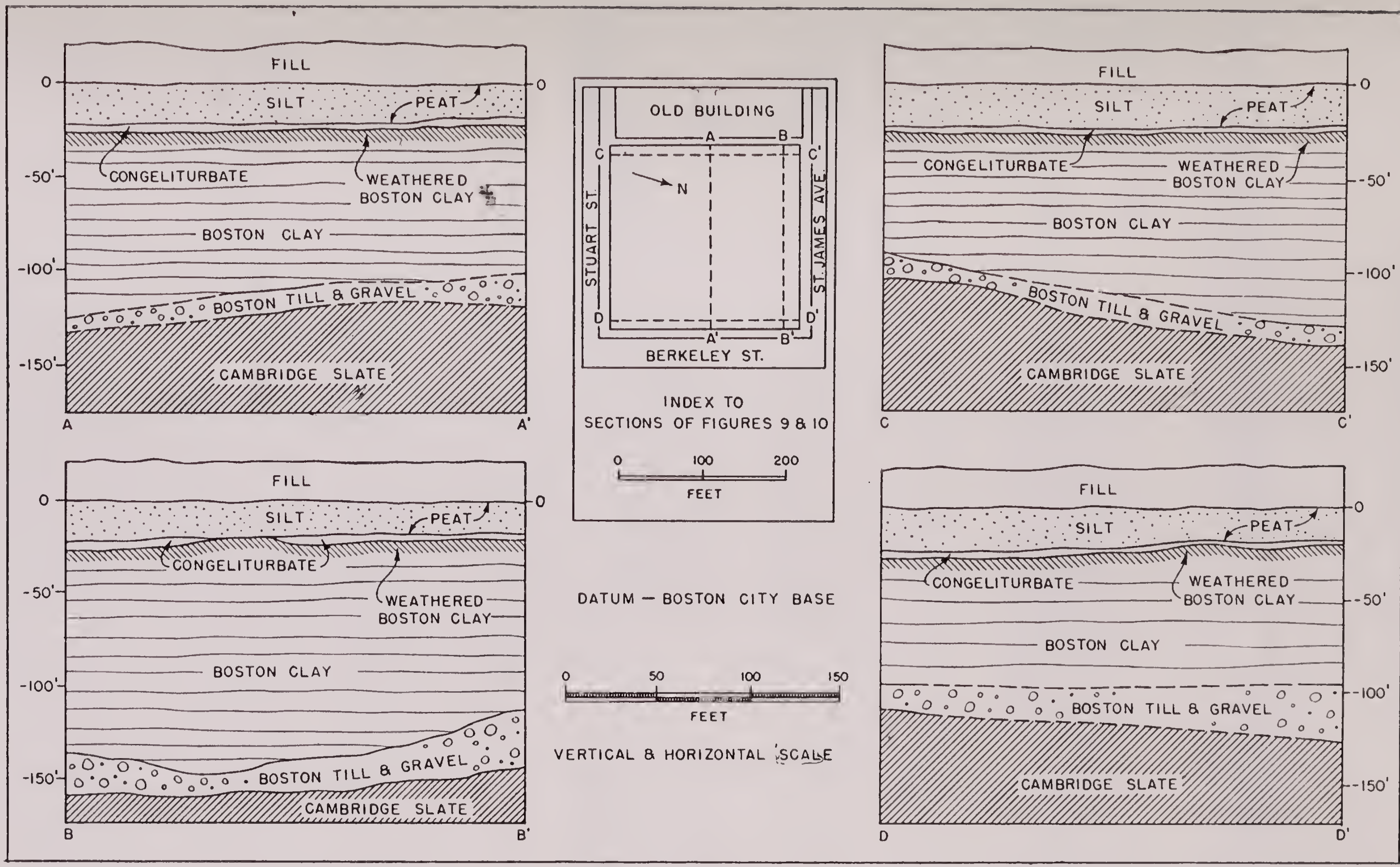


FIG. 9. Generalized Geologic Sections at the John Hancock Excavation. Lines of Section Indicated by Index.

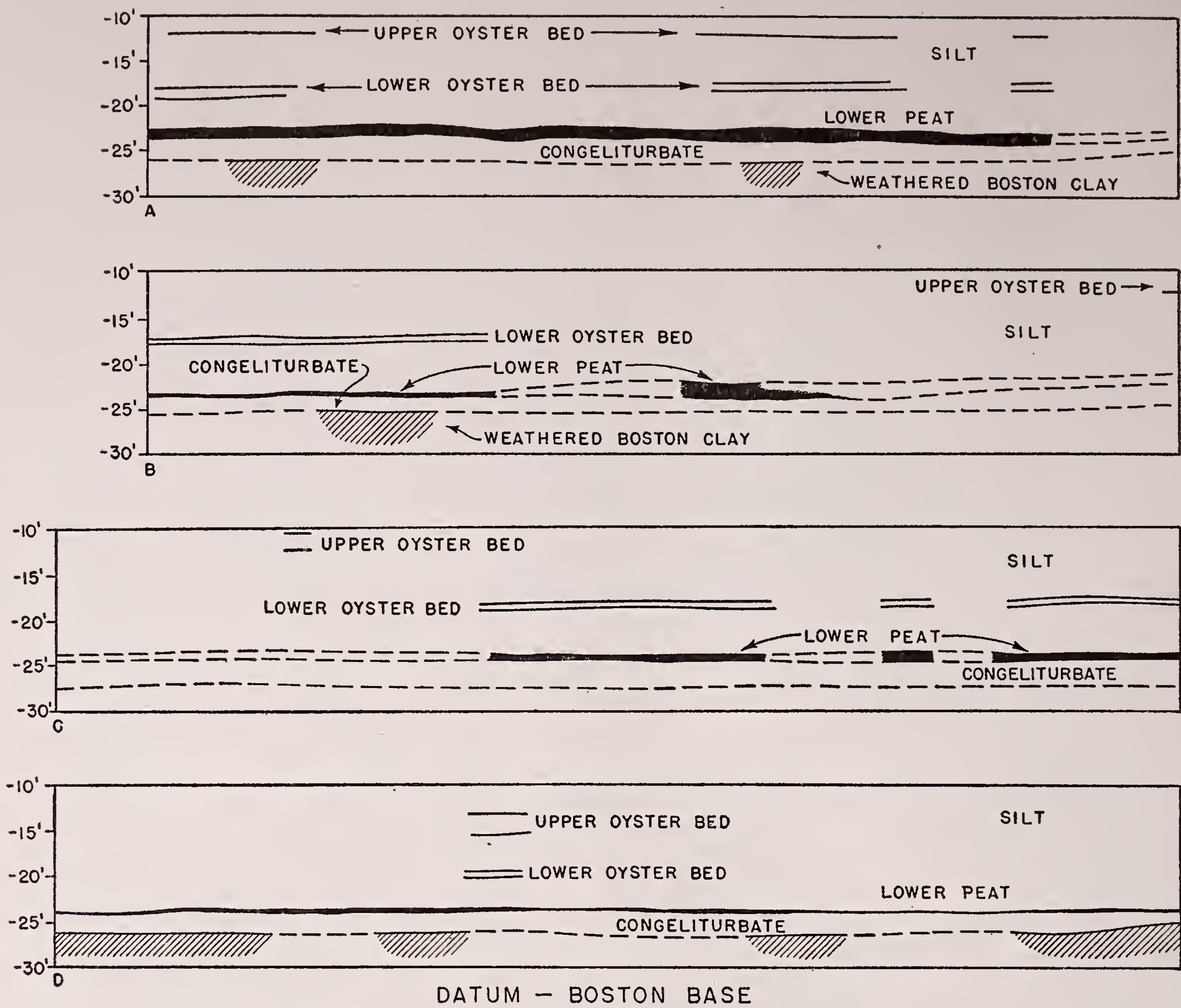


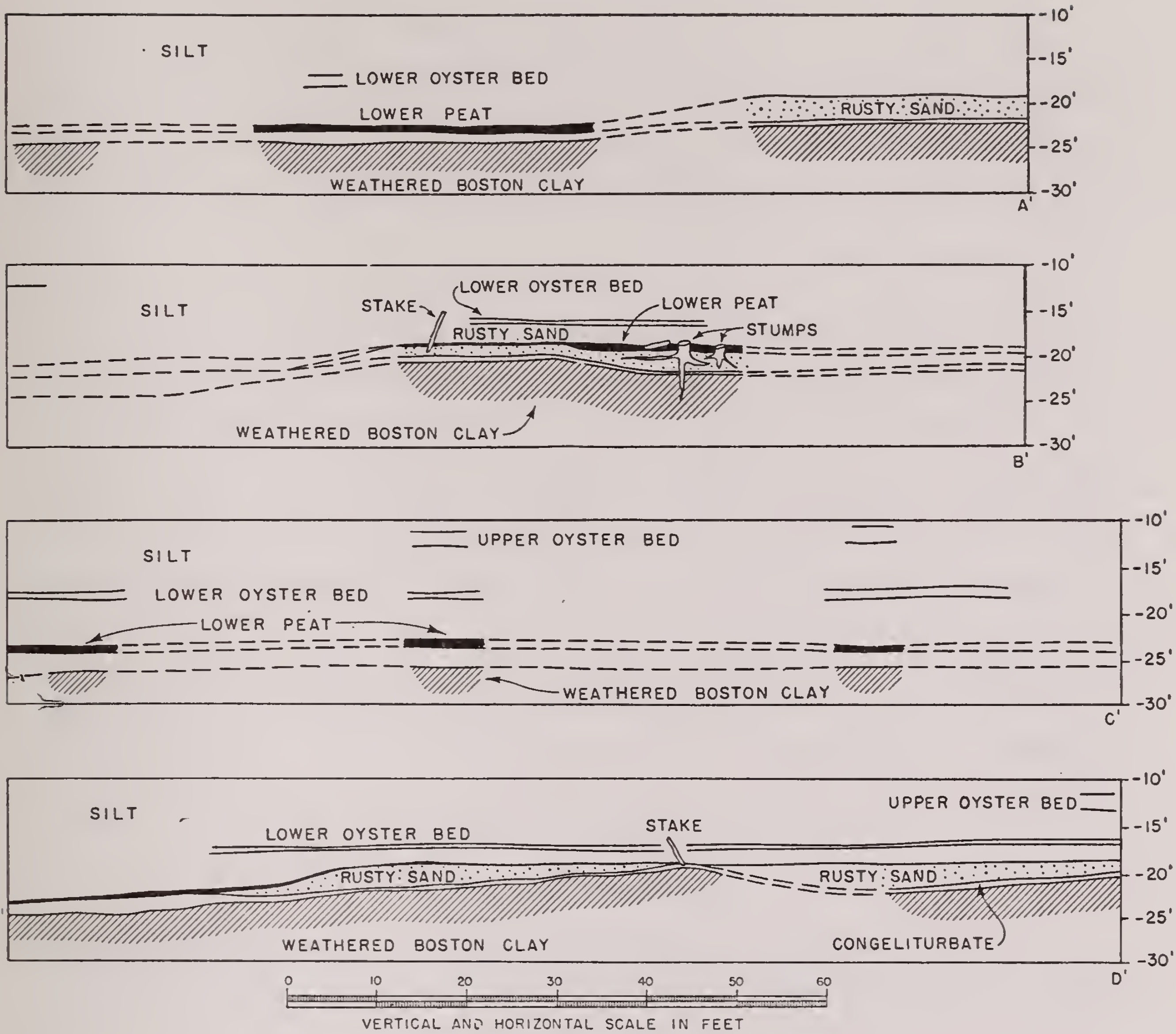
FIG. 10. Detailed Geologic Sections from -10 to -30 Boston Base at the John Hancock Excavation. For Location of Sections see Index, fig. 9.

character of the sequence from the top of the Boston clay to the fill, as seen along the same lines in the building excavation.

CAMBRIDGE SLATE

At the site, the Cambridge slate is presumed to form the north flank of an eastward-plunging anticline.[29] Cores of the slate, taken prior to foundation work for the new building show the slate to have a dip in excess of 60°. Although the orientation of the cores could not be established, the dip should be northerly if the structure is inferred correctly. The thickness of the Cambridge slate at this point is unknown, but at places in the Boston Basin it may exceed 3500 feet.[30] A dozen borings spaced over the building site show

[29] Billings, 1929. [30] La Forge, 1932, p. 44.



that the surface of the slate has a local relief of at least 30 feet and lies between −107 and −137 feet, Boston Base. Fresh surfaces of slate are characteristically gray blue in color. The specimens from the coring, however, show a somewhat lighter color as if slightly leached. They nonetheless indicate a hard, well-indurated rock, exhibiting the typical fine-grained texture and well-defined bedding of the Cambridge slate.

Boston Substage

TILL

A thin bed of glacial till was identified in the special coring made at the site. This undoubtedly coincides with the "hardpan" reported in the earlier holes drilled for the contractors. This till, not more than four feet in thickness, did not lie directly upon the slate, but was separated from it by about four

feet of coarse sand and a few inches of blue clay. The clay graded into the till. The till in the bore hole made for this study lay between −100 and −104 feet, Boston Base. The top of the hardpan reported elsewhere beneath the site varies between −92 and −132 feet, Boston Base. The till is blue in color and unweathered. It is a compact, poorly sorted deposit, with a high clay content.

CLAY

The clay grades downward into the till over which it lies. Here its known thickness varies between 67 and 104 feet. Its upper limit is sharply defined by an irregular surface lying between −27 and −21 feet, Boston Base, and sloping to the west and southwest. The clay is weathered to a yellow or a mottled blue and yellow color in its upper two to ten feet. Below this its color is the typical drab, olive green. Rock fragments ranging from pebbles to boulders weighing one-half a ton have been observed in the clay at the site. The mechanical analyses of the clay have been presented in an earlier section, and the microstructure of the weathered and unweathered zones previously discussed. Fossil content is discussed by Conger and Phleger elsewhere in this volume.

The Lexington Substage

THE CONGELITURBATE

On the irregular upper surface of the clay lies the congeliturbate previously described. It has a slight dip coinciding with the surface of the clay.

The Rusty Sand

This is a deposit confined to the northeastern section of the excavation. Its thickness varies, reaching a maximum of three feet, and averaging half that. The color is rusty, and the intensity of staining decreases with depth. It is a coarse sand, fairly well sorted and containing only a small percentage of fines, although the inclusion of clay clumps is common. Stumps of large trees found rooted in the top surface of this sand are described by Barghoorn. The sand is sharply delimited from the congeliturbate immediately below and is in turn overlain by a peat into which it grades.

The deposit is thought to be a local accumulation of material derived from upslope to the east and transported by slope wash. Its form suggests a low terrace, but it is not possible to trace its extent beyond the site. It may, in truth, be a small terrace formed around the sides of the sub-silt depression here present.

The Lower Peat

A peat bed spreads over the entire area of the site, resting in direct contact with the clay, or the congeliturbate, or the rusty sand depending upon the local distribution of those three deposits. Its lower contact is generally clean-cut, but where it overlies the rusty sand, it may in places be gradational. The upper contact may also be either sharp or gradational, in the latter case the peat grades into the marine silt. The upper limit of the peat lies between −18 and −23 feet, Boston Base, and it slopes gently toward the west. The thickness ranges from two or three inches to two feet or more. The color varies between black and brown, the former being characteristic of its basal portions, the latter of its upper. Its composition is also variable and tends to change with the color. Where well-developed, the lower horizons are a black amorphous peat which grades upward into a brown laminated peat at the top. Lenses of the rusty sand are found included in the amorphous layer. In those places where the peat is thinnest, it tends to express itself as a zone rich in humus containing a high admixture of silt. The tree stumps, previously mentioned, have been buried or partly buried by peat. Detailed studies of the peat show that the upper zone is salt-water and the lower, fresh-water in origin. The generally sharp lower contact and the inclusions of the underlying rusty sand point to moderate scouring by moving water in the lower section of the peat.

The Silt

A marine silt everywhere overlies the lower peat. Its contact with the peat is sharp in some places and gradational in others. The thickness varies between 19 and 23 feet. Its base lies between −19 and −23 feet, Boston Base, and its top is at approximately 0 feet, Boston Base. The physical characteristics of the silt have been described in an earlier section.

Shell material is distributed throughout the deposit. Two zones of oysters are recognized, one a discontinuous bed at approximately −17 feet, Boston Base, and the other a well-developed bed two feet in thickness between −11 feet and −13 feet, Boston Base. Both have a slight dip to the southwest. Although oysters are found as isolated individuals or clusters both above and below these levels, the two beds mentioned represent the greatest concentrations. A third mollusk bed, this one containing very few oysters, lies above the oyster beds, between approximately −5 feet and −8 feet, Boston Base. Fragments of driftwood are found scattered through the silt.

The Fishweir occurs in the lower section of the silt. The few stakes discovered in the excavation were located in the northeastern corner. They were driven into the silt and through the lower peat. Conditions of discovery

prevented observation of the tops of the stakes but the material found lay between *ca.* −21 feet and −19 feet, Boston Base. Twigs and small branches, presumed to be wattling, were found in a horizontal position at approximately −18 to −17 feet, Boston Base. At the New England Mutual site, the stakes were all cut off and their tops water-worn at a level between −12 feet 6 inches and −13 feet 5 inches. Whether this can be correlated with the better sorting and increasing coarseness of the silt which first expresses itself in the John Hancock excavation at this level cannot be determined. (See Fig. 7.) The pollen, diatoms, and foraminifera of the silt are described elsewhere by Wilson, Conger, and Phleger.

The Upper Peat

The silt grades upward into a brown to black, poorly developed, discontinuous, marine peat a few inches in thickness. It marks the position of the Back Bay of Colonial and later days. Artificial filling of this old Boston feature was begun in the mid-1800's and continued until the bay was obliterated and only the name remained.

Over this peat, or over the silt where the peat is absent, lies a thin skin of sand. This deposit may be related to the Old Boston and Providence Railroad trestle which extended across the northern limits of the excavation.

Made Land

The present surface of the Back Bay is the top of an artificial fill. At the site the fill is between 18 and 20 feet thick, giving it an elevation of the same figures above Boston Base.

Relation of the Sequence at the Site to the Areal Sequence

The relation of the geologic section as found at the John Hancock site to the sequence developed generally throughout Boston and vicinity is immediately apparent. The site sequence duplicates in many details that found elsewhere.

The till and clay of the Boston Substage are found at the site. The surface of the clay is weathered and eroded, a portion of a widely developed surface. The outwash of Lexington time is not present at the site, but it is reported in borings and excavations not far distant. Lexington time is represented at the site by the congeliturbate, a layer formed under the periglacial conditions then existing. The rusty sand is not immediately assignable to the areal sequence but is nonetheless easily explicable as a local postglacial deposit.

The lower peat is present, and although the fresh-water phase is not found in many places outside the immediate area of the site, it is explicable

in terms of local geography. An approximate equivalent of this fresh-water peat is found at the base of many of the modern marine marshes. The tree stumps at the site are to be assigned to the fresh-water bog. Marine silt is widely distributed throughout the Boston area, as is the upper peat. Only the pre-Boston till is missing, and, considering the paucity of its occurrence elsewhere, its absence is to be expected.

There is no possibility that the events recorded in the geologic section at the site are local and unique. On the contrary, they represent the same events widely recorded over the Boston Basin. Furthermore, there can be no doubt that the deposits at the site match those previously described from the Boylston Street site where the great bulk of the Fishweir has been found. Figure 11 is a section between the two sites. It illustrates that the section of the weir found at the John Hancock site occupies the same stratigraphic position as did the portions found in the Boylston Street subway and beneath the New England Mutual building.

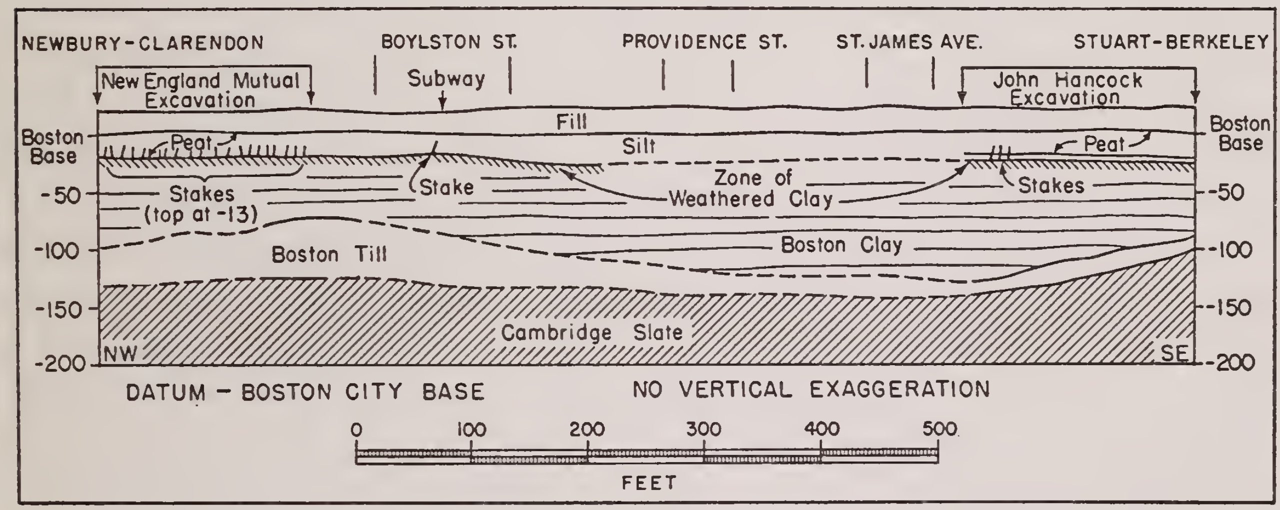


FIG. 11. Geologic Section Between the John Hancock Site and the New England Mutual Site.

RELATION OF THE PLEISTOCENE SEQUENCE OF THE BOSTON AREA TO THE PLEISTOCENE SEQUENCE ELSEWHERE

It has been established that the Fishweir occupies a restricted position within a local geologic column and that the events recorded in this column can be extended geographically into the general Pleistocene sequence of the Boston area. The relation, however, of the Pleistocene of Boston to established chronologies elsewhere is, at best, poorly known.

Over much of eastern Massachusetts, two tills, one certainly Wisconsin, and the other most probably Wisconsin, have been described.[31] The till of the Boston Substage is thought to be the equivalent of the so-called "older till" and the Lexington Substage is correlated with the "newer till". Glacial deposits which may be older than the "older till" of New England are described from Long Island [32] and from Cape Cod and Martha's Vineyard.[33] What relation they bear to the pre-Boston till described in this paper is unknown.

The terminal moraines of Long Island and southern New England bear a relation as yet not fully known to the Pleistocene of the Boston Basin. There is still considerable uncertainty concerning the interrelations of these terminal moraines. Furthermore, there is as yet no physical tie established between any of these deposits and those of the accepted sequences west of the Atlantic Slope. Until this tie is effected, and until the New England sequence is better established, all correlations with areas outside of New England must be based on educated guesses. Nevertheless, on the basis of weathering, the Lexington Substage appears to be late Wisconsin. The older Boston till, although more deeply weathered, seems also to be Wisconsin in age, although whether early or mid-Wisconsin it is impossible to say. The lack of any marked disintegration of the coarse component in the weathered zone would indicate that it is no older than early Wisconsin.

Even were the Boston geologic sequence unassailably extendable on a continental, or even a world-wide scale, little would be added to our understanding of the Fishweir, nor would an estimate of the geologic antiquity of the weir be affected. Therefore, because the problem at hand offers little justification for correlation outside of the immediate area, and because such a correlation could only repeat in part or in whole previous estimations, a geographic expansion of the Boston sequence is not here attempted.[34]

SUMMARY OF THE PLEISTOCENE HISTORY OF THE BOSTON AREA

Both occurrences of the pre-Boston till described previously are here considered, for no other reason than convenience, to represent a single ice advance. With this assumption in mind, it can be said that a considerable period of weathering immediately preceded this glaciation. The highly-

[31] Currier, 1941; Chute, 1940; Moss, 1943; White, 1947.

[32] Fuller, 1914; MacClintock and Richards, 1936.

[33] Woodworth and Wigglesworth, 1934.

[34] Bryan and Ray, 1940; Antevs, 1945; Flint, 1947, Table 8, pp. 270-271.

bleached Cambridge slate and the very fine till matrix testify to this. Furthermore, the shell material included within the till bears witness to a climate slightly warmer than today as well as to shallow-water marine deposits which probably resembled the recent silts. The interval between the

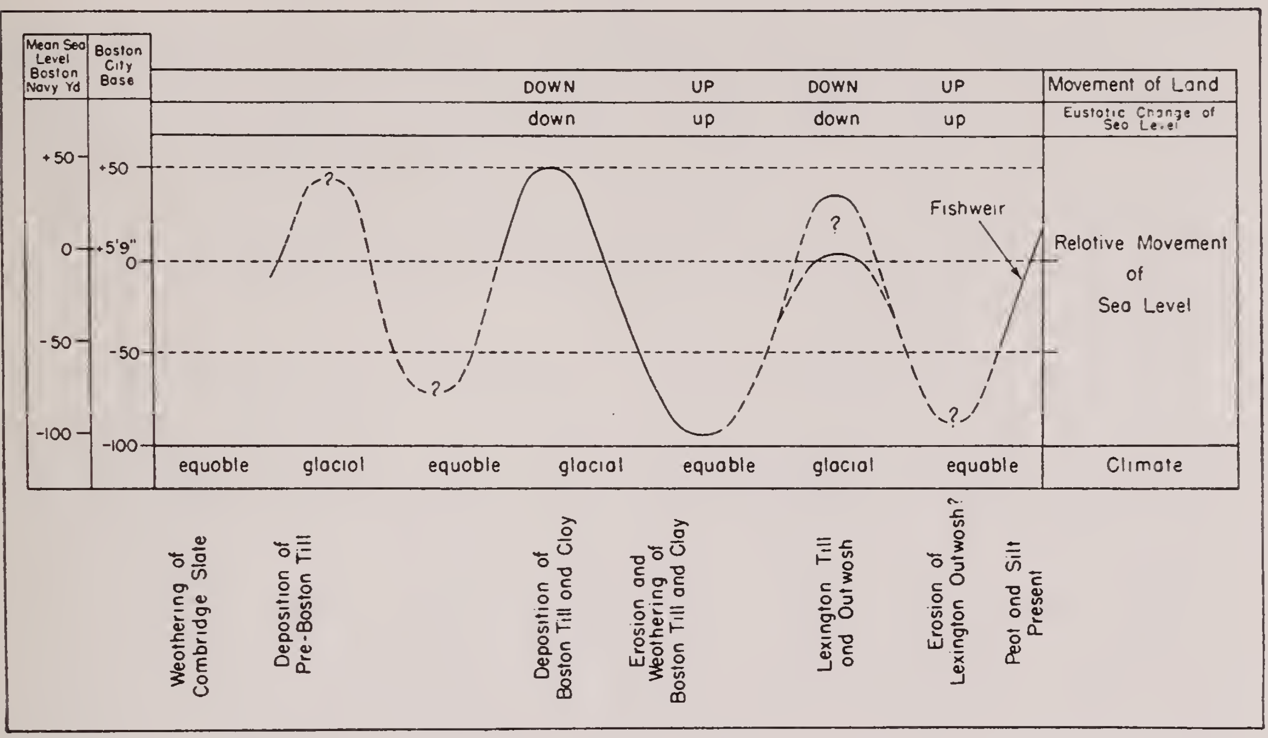


FIG. 12. Diagram to Illustrate the Changing Position of Land and Sea from Pre-Boston Time to the Present.

advance of this ice and that of Boston time is poorly known. From the shell material in the Boston till, it is obvious that the climate had ameliorated between the two glaciations and was warmer than the present. Furthermore, the areal distribution of the fossiliferous till suggests that marine sediments had accumulated outside a shore having a pattern not too different from the present. Figure 12 illustrates the varying relation of land and sea to Boston time and for the succeeding periods to the present.

The ice of the Boston Substage advanced across the area in a direction somewhat south of east. It plowed into the bay sediments and incorporated much shell material into the till which it eventually deposited. It seems probable that some of the till, particularly that now found along the bedrock valleys, was deposited beneath the sea level of the time. Till took the form of drumlins over the bedrock highs. As the ice withdrew, uncovering the Boston Basin, water-laid sediments were deposited. Sand and gravel

were first laid down. This was followed by a glacial clay. Sea level at this time stood at a position between 30 and 40 feet, probably more, above the present strand. This change in the relation of land to sea was presumably due to a downwarping of the land under the ice load, and not to a eustatic rise of the sea because the waters were still cold and the ice had withdrawn only a short distance.

Following the withdrawal of the ice, the land recovered from its downwarping. The clay was exposed to concurrent subaerial weathering and erosion. During the interstadial conditions existing at this time, a high sea level would be expected. This was not the case, however, and the 90 to 100 foot decrease in the level of the sea below its present height must be an expression of a rising land, recovering from the downwarping suffered during the Boston Substage.

The ice of the next glacial advance, the Lexington Substage, failed to cover the eastern Boston lowlands. The ice stood along the northern edge of the Basin, and a tongue reached the Fresh Pond area of Cambridge. It covered most of Brookline and all of the Newtons. From here its front swung in a southeasterly direction. Raised beaches and outwash-filled valleys indicate that sea level stood between 40 and 50 feet above its modern limit, at least during the waning stages of this glaciation. There appears to be some evidence that the Lexington outwash was later graded to a sea level approximating that existing at the time of the erosion of the Boston clay. In any event, a rising sea is the event next recorded. It follows that the sea must have fallen from its glacial high. It will be noted that the sequence of high glacial sea and low non-glacial sea is here repeated for at least the second time. This anomaly can be explained only by downward movement of the land under ice load, with recovery of the land following deglaciation. Such movement was great enough to more than counterbalance the accompanying eustatic changes in sea level.

Peat, some 50 feet below the surface of Boston Harbor, is the lowest recorded shoreline following the Lexington Substage. From this point, and probably from much lower, the sea rose continuously to its present level, depositing peat along the shoreline and silt offshore. The formation of a marine peat, the upper peat, continues to the present day and keeps pace with a slowly rising sea.

Thus, at least three glaciations are recorded from the Boston area. Of these, the last two are the best known. They were accompanied by a high sea level which resulted from downwarping of the land under the load of glacial ice. Each was followed by a low sea level consequent upon the uplift of the land with the melting of the ice and the release of load. From this low

sea level following the last glacial advance, the marine waters have been rising to the present day. This swinging sea level is summarized in Figure 12.

PHYSICAL SETTING OF FISHWEIR TIME

It has long been recognized that the Fishweir was built at a time when sea level stood below that of the present. It has been estimated that mean low water stood at –15 feet 8.9 inches, Boston Base, during weir construction.[35] Silts and peats have since covered the weir and obliterated the relations of land and water existing at that time. Man's activity has further obscured the physical setting of Fishweir time.

The map reproduced as Figure 13 has been prepared on the assumption that Johnson's estimate of the Fishweir sea level is essentially correct. The low-water line at the time of the construction and operation of the weir was determined by the intersection of the –16 foot, Boston Base, contour with the surface invaded by the rising sea which laid down the silts and salt-water peats. (See Fig. 6.) All the area below this line was submerged at low tide, all above was dry land. High tide mark on the map is equivalent to the contour of –6 feet, Boston Base, on this same surface. This figure is based on the assumption that the mean tidal range in this area approximated that in the Charles River estuary prior to its recent damming. This figure, 9 feet, 6.7 inches, was reported to W. O. Crosby.[36] Unfortunately it has been impossible to reconstruct the submarine contours on the floor of the Back Bay of Fishweir time.

The Back Bay of Fishweir time was considerably restricted in area as compared to the Back Bay of Colonial days. The embayment expanded southward from a mouth which varied between 1000 to 1700 feet in width at low and high tides respectively. Its main channel lay between Clarendon and Dartmouth Streets and ran between Commonwealth Avenue and Boylston Street. The shoreline of the bay itself had the irregular pattern expected along a drowned coast. At high tide, a low, narrow island lay just north of Beacon Street and the main channel of the Charles River estuary. At low tide, a small bar was exposed along Clarendon Street, off the northwest corner of the present site of the New England Mutual Life Insurance Company building.

The stakes thus far found have been located along the northeastern shore of the embayment (Fig. 13). With the exception of a few stakes found in the southeast corner of the New England Mutual excavation, all lay just out-

[35] Johnson, et al, 1942, p. 162.
[36] Crosby, W. O., 1903, p. 11.

Fig. 13. Map to Represent High and Low Water Marks During Fishweir Time and the "Zone of Preservation."

side the low-water mark. Extensive excavations, however, have yet to be conducted between high- and low-water marks.

From a consideration of the distribution of land and sea of Fishweir time, it seems safe to assume that the weir had some relation to the embayment as a whole. Presumably fish entered the embayment on the flood tide, probably through the Dartmouth-Clarendon channel and were guided by "leaders" as yet poorly defined into one or more cul-de-sacs as yet unlocated. The inability, however, to establish the submarine topography of the old Back Bay and the lack of significant pattern to stakes already found makes it impossible to analyze at present the method in which the weir utilized the local geographic conditions.

The land above high water of Fishweir time was undoubtedly utilized in one way or another by those who built and used the weir. A portion of this surface was subsequently flooded and buried by peat and silt, the extent of such flooding being marked by the Colonial shoreline. It is, then, in the area between the high tide marks of Fishweir and Colonial times that the campsites, middens, artifacts and other traces of the Fishweir people are most likely to be preserved. Land above the Colonial shoreline has been subjected to intensive disturbance by the present occupants and, undoubtedly, to some extent by the Indians who immediately preceded them. It is, therefore, in this "zone of preservation" (Fig. 13) that it is most likely that future excavations will uncover the most tangible indications of the culture possessed by the people who built the weir.

THE AGE OF THE FISHWEIR

The foregoing account of the Pleistocene chronology in the Boston area developed in this study produces nothing that is startling concerning the antiquity of the Boylston Street Fishweir. At best, the geologic study makes more certain that the estimates already made as to the age of the structure are of the correct order of magnitude.

It can be said, however, that there is now no doubt that the Fishweir was constructed sometime after the last glacial advance in this area. The structure is entombed in sediments laid down by a sea whose rise continues to the present day. The rise of the sea from Fishweir time to the present represents but a fraction of the total time involved during a much longer and continuous rise which began at some unknown time after the last glaciation of the area. Faunal and botanical studies reported elsewhere in this volume and in the previous study indicate that the climate during fishweir construction and operation was not much different from that of the present. If anything, it may have been a little warmer. At the same time, however, there is no evi-

dence that the "Postglacial Optimum" intervened between Fishweir time and the present. Rather, it is probable that this period of excessive warmth preceded Fishweir time. The climax of the "Postglacial Optimum" is well dated in Europe as falling between B.C. 4200 and 4300 or 6100 and 6200 years ago.[37]

Shimer[38] suggests that the weir was constructed 2000 to 3000 years before our time. Knox assigns an antiquity of from 3300 to 3600 years.[39] Benninghoff presents data which would give a date approximating that originally advanced by Shimer.[40] On the basis of the geologic evidence, no one date can be given preference over the others, nor is a new estimate geologically justified. The dates already suggested are of the correct order of magnitude.

ACKNOWLEDGEMENTS

The authorities of the Robert S. Peabody Foundation for Archaeology and The Viking Fund made available funds for the partial support of this study. Prof. Kirk Bryan, Harvard University, has provided invaluable criticism and encouragement in both the field and office phases of this study. I am greatly indebted to the other contributors to the general study: Prof. L. R. Wilson, University of Massachusetts; Prof. Fred B. Phleger, Amherst College; Prof. Elso S. Barghoorn, Harvard University; Mr. Paul S. Conger, U.S. National Museum, and Frederick Johnson, Peabody Foundation. To Mr. Johnson, under whose direction the general investigation has been carried on, I owe not only a free hand in my own study but also many friendly and stimulating conversations. His patience, understanding and good humor made the project a most pleasant experience from its very inception.

The representatives of the Turner Construction Company, at both the John Hancock Life Insurance Company and the New England Telephone and Telegraph Company projects, facilitated by their interest and cooperation important phases of the field work. The Boston Society of Civil Engineers made available its invaluable catalogue of boring records from the Boston area.

Dr. L. W. Currier, United States Geological Survey, who for many years has directed glacial studies by the Survey in Massachusetts, kindly offered suggestions on the manuscript. Several of these have been adopted. The decision to name the glacial substages in this paper, however, has not been abandoned despite his feeling that the decision is unjustified.

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[37] Fromm, 1938 and Welten, 1944. [38] Shimer, 1918, pp. 460; 462.
[39] Knox, 1942, p. 126. [40] Benninghoff, 1942.

PALEOBOTANICAL STUDIES OF THE FISHWEIR AND ASSOCIATED DEPOSITS

ELSO S. BARGHOORN

INTRODUCTION

REOPENING of an extensive area underlying the Back Bay district of Boston afforded an unusual opportunity for a thorough examination of the paleobotanical and geological relations of the Boylston Street Fishweir. The area uncovered in the course of construction of the John Hancock Insurance Building, although several hundred feet southeast of the former site, represents essentially the same stratigraphic sequence described in previous accounts.[1] Owing to successive exposure in vertical section of virtually the entire area excavated in 1946 it was possible to make repeated observations and to secure numerous collections from critical levels in the plant-bearing deposits. Because of the completeness of the material collected and the opportunity to make detailed observations of plant remains *in situ* it has been possible to reconstruct in some measure of detail the vegetational development and related ecological changes preserved in the organic sediments associated with the Fishweir. In addition, specimens of wood from various levels of the new site have proven to be of great interest in investigations of the degradation of plant tissues and the physical and chemical changes attending preservation and degradation of the plant cell wall. Inasmuch as the two phases of paleobotanical study of the site differ widely in their general interest and methodology they will be dealt with separately.

PART I

THE FISHWEIR AND ASSOCIATED ORGANIC SEDIMENTS

Plant remains collected for identification, anatomical, and chemical studies were obtained from the following recognizable levels of the site:

a) Roots and stumps *in situ*, representing vegetation existing before the formation of the Lower Peat.

[1] Johnson, et al, 1942.

b) The Lower Peat. This organic layer is of varying thickness and diverse botanical composition but extends over the entire area of the excavation.

c) The Fishweir. Stakes and wattles of the weir were found only in the extreme northeast corner of the excavation.

d) Marine silt overlying the Fishweir. The silt layer, which is easily differentiated from underlying deposits is of considerable thickness and contains a few plant remains represented by drifted stumps and branches (Table IX). Occasionally mid-tide salt-marsh peat was found *in situ* at the base of the marine silt. High tide salt-marsh peat was found in irregular masses and pockets throughout the lower portions of the silt.

In addition to specimens from these various "strata," samples were collected from several spruce pilings exposed during the course of excavations. The piles were driven approximately 100 years ago in constructing the Boston and Providence railroad across the Back Bay area. The piles consisted of well-selected sound wood exposed in their length to the environment of the various levels of the deposit. Hence, they provided a fortunate means of measuring the rate and mode of degradation of coniferous wood submerged under known environmental conditions during an appreciable length of time, and in addition provided an interesting comparison with the rate and extent of decay of various woods comprising the Fishweir.

The relations of the various "strata" and structures of the site are shown diagrammatically in Figure 10.

The Stakes and Wattles

Remains of the aboriginal Fishweir occupied the center of interest in botanical studies of the Boylston Street site. An estimated 65,000 stakes were exposed during the course of excavations in 1939. In the recent excavation, little additional evidence of the Fishweir was exposed, indeed only a very few specimens of the stakes and wattles were found. These comprise 15 specimens, of which eight were stakes and seven wattles. All but one of the species represented was previously identified among collections of the Boylston Street Fishweir.

Samples of the 15 stakes and wattles recovered from the John Hancock Building excavation were preserved in alcohol and subsequently dehydrated and embedded in paraffin or celloidin. The embedded specimens were sectioned on a sliding microtome in the transverse, radial and tangential planes. For purposes of accurate identification and for photomicrography the thin sections obtained were stained in Haidenhain's iron-alum haematoxylon

and safranin. All the specimens were identified with certainty by the characteristic structure of their woody tissues; doubtful determinations were verified by careful study of the pith, the number and arrangement of leaf traces at the nodes, or structure of the bark.

Because of the paucity of information regarding the Fishweir itself in the recent excavation, it seems desirable to integrate results of the study of the stakes and wattles from the two sites. Table III summarizes identification of all species collected from the Fishweirs in both excavations. A total of eighteen genera and twenty-one species of trees and shrubs are represented in the combined collections.

As pointed out in the previous investigation of the Boylston Street Fishweir, there seems little evidence to indicate that the Indians made a qualitative selection of woods on the basis of their physical properties when choosing materials for the construction and maintenance of their weir. It seems more likely that the extensive use of certain species was determined largely by their availability in convenient size. For the stakes of the weir, straight young saplings of sassafras, oak, alder, and beech were chosen. Branches removed in trimming the sapling trees were apparently utilized as wattles in perfecting the weir.

Because of the selective factor of availability in the immediate environment, the woody flora represented in the Fishweir cannot necessarily be interpreted as indicating greater or lesser abundance of certain species in the flora of the Boston Basin at the time the aboriginal Fishweir was in use. Similarly, the absence of certain species such as chestnut, white pine and tupelo does not indicate actual scarcity of these species in the primeval vegetation of eastern Massachusetts. All the trees and shrubs represented in the Fishweir occur in the existing flora and may be found today in relatively close association in lowland areas of eastern Massachusetts. The extraordinary abundance of sassafras and the rather high percentage of flowering dogwood seem anomalous. However, the frequency of these two species is of doubtful importance in reconstructing the pre-colonial flora in view of great changes in the native vegetation brought about by white settlement. In this connection it is significant that sassafras was very extensively collected for medicinal purposes in the eastern American colonies, and great quantities of the roots were shipped to European markets.

The available evidence deduced from a study of the woods represented in both excavation sites indicates that the flora was essentially similar to that at the time of white settlement in the Boston area. There is no evidence from the stakes or wattles of any significant climatic change since the Fishweir was constructed.

TABLE III. GENERA AND SPECIES OF TREES AND SHRUBS REPRESENTED IN THE FISHWEIRS ON BOYLSTON AND STUART STREETS

Scientific Name	Common Name	No. of Wattles	No. of Stakes	Total No.
DICOTYLEDONS				
Sassafras variifolium (Salisb.) Ktze.	Sassafras	6	40*	46
Quercus	Oak			
	red-black-type	4	19	23
	white oak type		1	1
Alnus	Alder	4	14	18
Fagus grandifolia Ehrh.	Beech	7	6	13
Betula	Birch			
	gray type		4	4
	black-yellow type	3	1	4
Cornus florida L.	Flowering Dogwood	1	6	7
Ostrya virginiana (Mill) K. Koch.	Hop-hornbean	2	5	7
Carya (either *alba* or *ovata*)	Hickory	5	8	13
Acer	Maple			
	soft maple type	1	4	5
	hard maple type		2	2
Fraxinus americana L.	White Ash		5	5
Myrica pennsylvanica Loisel.	Bayberry	3		3
Clethra alnifolia L.	Sweet Pepperbush	2		2
Platanus occidentalis L.	Sycamore		1	1
Populus	Aspen	1		1
Salix	Willow	1		1
Ilex glabra (L.) Gray	Inkberry	1		1
CONIFERS				
Larix laricina (Du Roi) Koch.	Larch		1	1
Tsuga canadensis (L.) Carr.	Hemlock		1	1
Totals		41	118	159

* In the 1942 study 60 additional stakes were identified as sassafras, beech, or oak. These were not preserved for anatomical study.

Development of Vegetation in the Area Prior to Construction of the Fishweir

From accumulated evidence derived by the identification of plant remains in various sections of the Lower Peat it has been possible to determine a reasonably complete sequence of major changes in the vegetation prior to the aboriginal occupation. Re-examination of peat samples collected in the Boylston Street excavation and their comparison with those from the Stuart Street excavation indicate a considerable range of plant constituents, and hence, of ecological conditions at contemporaneous levels of development in the area as a whole. Local and varied ecological conditions were clearly evident in exposed sections in the Stuart Street excavation. In various parts of the area, the physical character of the peat, its thickness, mineral content and botanical composition differed markedly, indicating diverse environmental influences in its formation. The botanical evidence is completely in harmony with the geological interpretation of the area outlined by Judson, since it was found that areas of lower elevation in the original basin, as indicated by Judson's contours (Fig. 6), correspond to areas in which the peat flora represents a more hydrophytic or wetter phase of marsh vegetation. Additional correlation of geological and botanical evidence was secured by re-examination of the peat collected in 1939 from the Boylston Street excavation. Detailed study of this peat showed that it was composed chiefly of the remains of rushes (*Scirpus*), embedded in a matrix composed largely of mineral sediment. Both observations indicate that the peat was formed in an environment of abundant seasonal flooding and relatively high level of the water during the summer months. The more fibrous samples of peat from the Stuart Street site, on the other hand, show a very high percentage of organic matter, a low mineral content, and the presence of typical reed swamp plants of less hydrophytic habitat—*Phragmites* associated with sedges and ferns. The majority of the Stuart Street peat sections accordingly indicate drier conditions of marsh vegetation than do available collections of peat from the original Boylston Street site. This difference is quite consistent with the presumed elevation of the two areas in relation to the ancient Charles River, which apparently, seasonally inundated the entire area.

In the progress of these studies, it became evident that various stages of vegetational development in the area as a whole could not be reconstructed from a single, even though representative section of the peat. Accordingly, a series of observations were made during excavation of the Stuart Street site in order to determine both the general sequence of vegetation com-

prising the peat and any possible evidence of vegetation existing before formation of the peat.

A priori it seems evident that the general sequence of vegetation in the region is one of increasingly hydrophytic environment, culminating eventually in submergence and marine invasion of the entire area. To a great extent, the paleobotanical evidence supports such an interpretation. However, this sequence of events, which may seem simple in terms only of land-sea level relationships, is exceedingly complex ecologically. It is the direct reverse of the "normal succession" of vegetation on a depositing shoreline. In a so-called "normal succession" the land flora gradually invades the more hydrophytic or aquatic phases of the environment and gradually establishes a more and more mesophytic vegetation. Such a succession might eventually develop on a static shore or coast line, as has been suggested in various ecological studies.[2]

Vegetational "succession" in the areas exposed by the building excavations not only demonstrates a uniform reversal of the "normal hydrosere" sequence, as shown by a consistent and harmonious trend toward wetter and more saline plant communities preserved in the peat, but also indicates that the wet meadow and marsh phase was of brief duration. There is no evidence

[2] Nichols, 1920; Tansley, 1939.

PLATE II

Plant Remains of the Lower Peat and the Fishweir

1. Unidentified plant fragment showing preservation of the delicate cell walls of a growing point. Thin section of peat (15 μ). X 42.
2. Oblique longitudinal section of a root showing preservation of the primary walls of cortical cells. Note the vestiges of protoplasmic contents. Root remains such as these show conclusively that the peat is in part an autochthonous deposit, since the roots represent plants which grew on a peat-forming marsh. X 96.
3. *Ulmus americana* root. Tangential longitudinal section of root wood showing advanced stage of degradation by fungi. Specimen from the base of the Lower Peat. X 96.
4. Microtome section, fibrous strata of the Lower Peat. Note the lamination resulting from successive layers of compressed plant remains. Scattered throughout the organic mass are sclerotia and spores of fungi. A large component of this fibrous peat consists of "amorphous" organic residues. X 48.
5. Microtome section of fibrous peat, showing a root in oblique longitudinal section. Relation of the root to the surrounding peat indicates the *in situ* development of the root system in the peat. X 48.
6. *Ilex glabra*. Tangential longitudinal section of a wattle from the Fishweir. Black contents in the lumen of the vessel in the center of the figure are chiefly particles of iron sulfide. X 96.

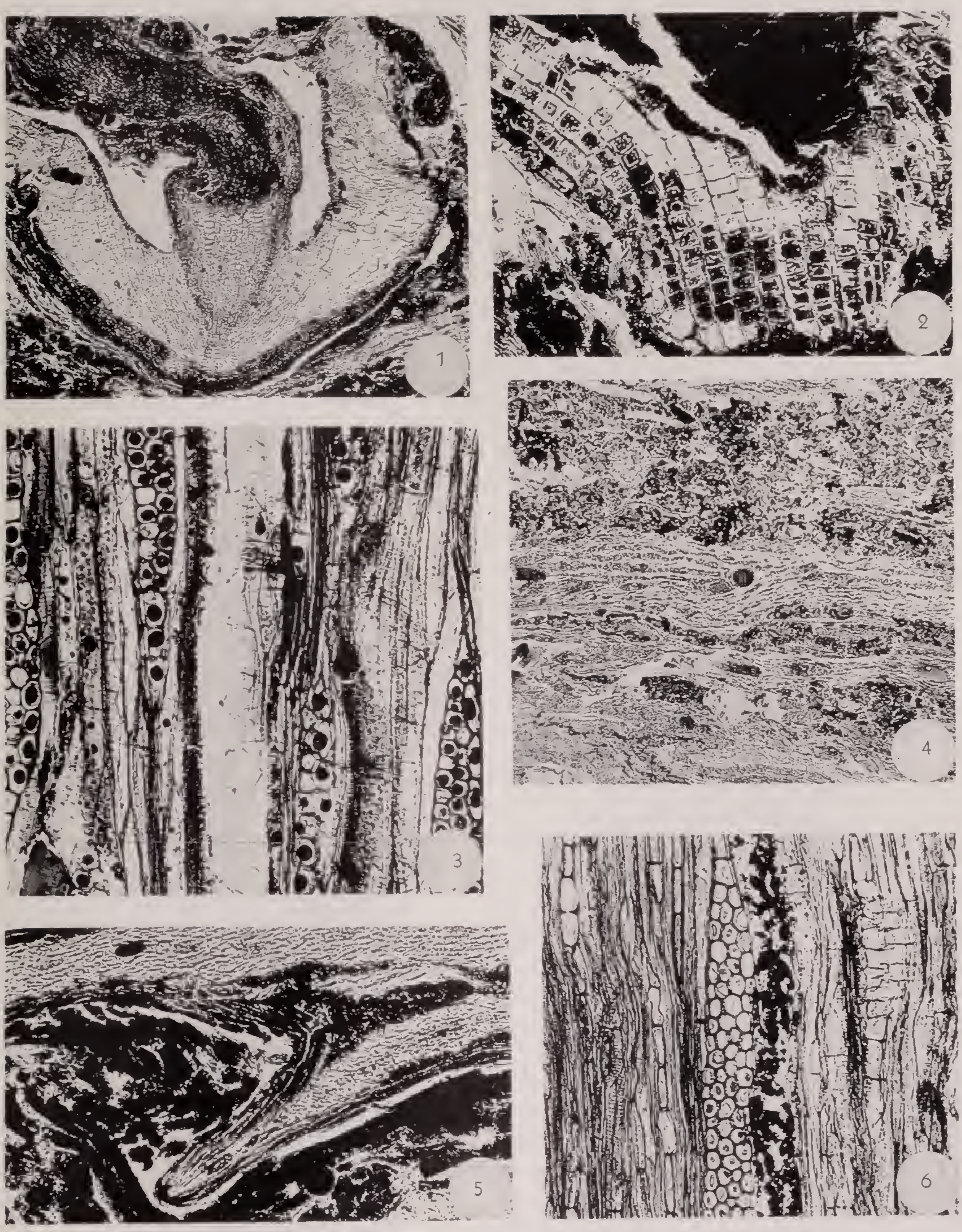

Plate II

(See opposite page for explanation.)

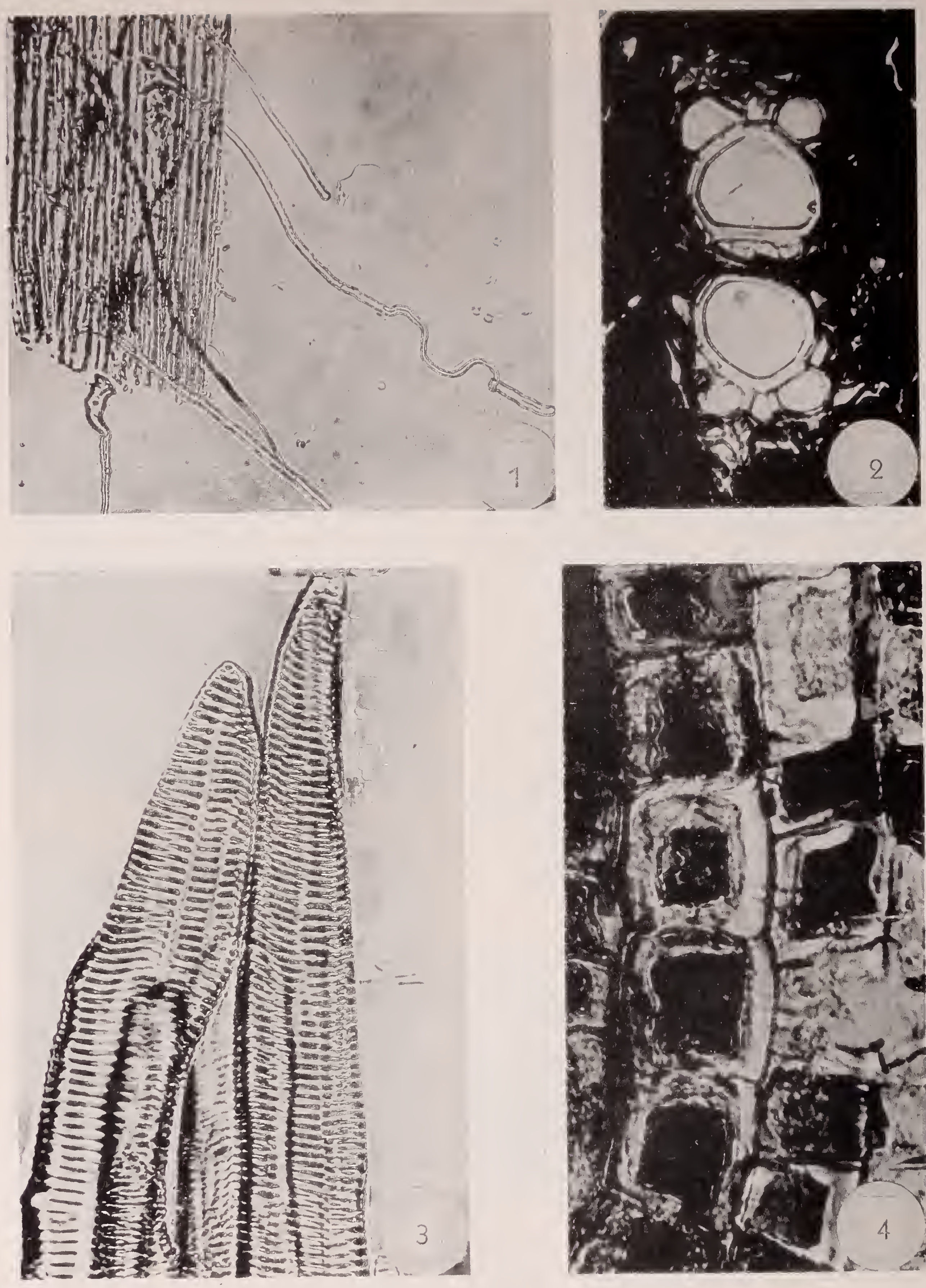

PLATE III

(See opposite page for explanation.)

of gradual submergence of the peat-forming basins on which the weir was eventually built. As indicated in Figure 14, and by examination of numerous profiles of the Lower Peat, the vertical extent of this peat was quite small throughout the entire area. Since there is no evidence of subaerial erosion of the upper levels of the fresh (and brackish) marsh peat before marine invasion, it seems reasonable to conclude that the amount of peat formed before the rising water level terminated its development was relatively small. In this connection it is interesting to note the occurrence of sporadically distributed thin layers of typical salt-marsh peat (*Spartina alterniflora*) resting on the fresh-water marsh peat which comprises the major portion of the Lower Peat layers. This relation of the contrasting types of peat (fresh-water and salt-marsh) is evidence of quite rapid vegetational change. If the area had at one time been a shallow and irregular basin bordering the ancient Charles River estuary, a rapid change in the flora might have resulted from the breaching of higher land protecting the basin from the river. In the early stages of this marine invasion there would have been a shift from the original fresh-water wet meadow vegetation to a brackish marsh vegetation. This would be followed by more and more saline conditions with the quite rapid transition to mid-tide salt-marsh vegetation, dominated by *Spartina alterniflora*. As the tidal influence increased, with further submergence, peat accumulation would cease and marine silting would dominate the sedimentation. Such a sequence of events seems to be clearly indicated in the Back Bay area, if

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PLATE III

Preservation of Plant Tissues in the Lower Peat.

1. Portion of root of *Juncus* sp. isolated from the Lower Peat, showing preservation of delicate tissues composed chiefly of cells possessing thin primary walls. Heavily lignified secondary walls of mechanical and conductive tissues in the center of such roots are highly degraded. A large portion of the Lower Peat is composed of root systems of sedges and grasses exhibiting structural preservation of the type shown in figure 1. Note preserved root hairs. X 200.
2. Transverse section of a fern root from the Lower Peat. Dissection of the peat shows that fern roots and root systems developed *in situ* in the peat and are not allochthonous in origin. The *in situ* nature of the fern root systems is conclusive evidence of fresh water marsh conditions during accumulation of a large portion of the lower peat. X 300.
3. Isolated tracheids from fern roots shown in figure 2, delignified by treatment with sodium chlorite. Note structural preservation of the cell walls. The walls of such cells exhibit many of the optical and chemical properties of unaltered cellulose despite their incorporation in the peat at the time of its formation. X 300.
4. Longitudinal section of meristematic tissue of a root apex in the Lower Peat. Note retention of a structural residue of the thin primary walls; also the preservation of what appear to be modified cell contents. X 750.

a composite and integrated interpretation of the various peat profiles is made. This interpretation is well supported by Judson who shows that the area was a basin which was flooded by water flowing first across the low saddle between Clarendon and Dartmouth Streets (Fig. 6).

A major question remaining in these efforts to reconstruct the general physical and biological history of the area centers on the problem of the vegetation existing before the early stages of peat formation. Geological interpretations indicate that the irregularly weathered surface of the underlying glacial clay is largely overlain by a congeliturbate layer presumably formed during periglacial climate. In certain areas of the John Hancock excavation, an additional deposit was found intercalated between the congeliturbate and the overlying peat, which elsewhere is in direct contact with either the clay or congeliturbate. This additional layer is designated by Judson as the Rusty Sand. It is a loose deposit of varying thickness, averaging about 18 inches in vertical extent and grading upward imperceptibly into the Lower Peat.

The Rusty Sand layer is of great interest in reconstructing the general vegetational sequence of the Back Bay area, since the deposit contains abundant remains of the earliest flora represented in the various sections exposed to study. These remains are in the form of large stumps, of which nine were found in the John Hancock excavation, rooted *in situ* on the upper surface of the Rusty Sand. The stumps provide conclusive evidence of a tree vegetation preceding invasion of the area by fresh-water marsh plants and the consequent formation of peat. Identity of the stumps is particularly interesting, and lends support to the view that originally the area was a poorly-drained, partially-wooded basin, on the sandy and drier areas of which grew thin stands or isolated individuals of lowland forest trees and shrubs. Eight of the nine stumps found *in situ* proved to be those of white oak (*Quercus alba L.* or possibly *Q. bicolor Willd*).[3] The other large stump was that of red or swamp maple (*Acer rubrum L.*). Both these trees are common in wet, seasonally-flooded woodlands of eastern New England. The oak and maple stumps were found in the northeast corner of the John Hancock excavation, a portion of the site in which the Rusty Sand layer was of greatest thickness. Subsequent careful examination of other parts of the excavation in which the sand layer is much thinner yielded fragments of roots and stems of both elm (probably *Ulmus americana* L.) and the swamp buttonbush (*Cephalanthus occidentalis* L.). Although it could not be conclusively proven, because of unfavorable exposure of the strata, the roots of the latter two species appeared to be in their original position,

[3] The wood of these two white oaks cannot be distinguished with certainty, particularly in the condition in which they were found.

embedded in the substratum. Elm, and particularly buttonbush, are likewise common elements of the swampy woodland flora and comprise, with oak and red maple, a rather consistent picture of the vegetation and general ecological conditions of the area before development of the reed-swamp and sedge-meadow peat deposits (Table IV).

The relation of several of the large oak stumps to the underlying strata is shown in the generalized diagram (Fig. 14). The root system of the largest stump was traced downward in the massive blue clay for a distance of about 5 feet below the base of the stump. The tree had developed a tap root with strong dominance in growth as shown in the diagram. The tap root and other deep roots had grown preferentially into conspicuous joints in the clay. Adjacent to the tree roots, and completely ramifying into the upper layers of the buried "soil" down to the blue clay, innumerable profusely-branched root systems were found. These root systems are not those of trees or shrubs but rather of various genera of the Cyperaceae (also Juncaceae?) and represent herbaceous vegetation contemporaneous or subsequent to the trees. Structural preservation of these roots is very poor, in contrast to comparable remains in the peat. The root systems perhaps represent vegetation existing during earlier phases of conversion of the area into wet meadow. The depth to which both tree roots and the herbaceous roots penetrated is of much interest in connection with the possible height of the water table at the time these plants occupied the soil surface. Lack of information concerning the identity of species of the herbaceous plants eliminates the possibility of direct correlation with present day ecological conditions under which these same species grow. However, the vigorous development of oak roots at considerable depth in the clay is a fairly reliable indication that the surface

Table IV. Genera and Species of Trees and Shrubs Represented at the Base of the Lower Peat*

Scientific Name	Common Name	Number and Type of Specimen
Quercus (*Quercus alba* L. or *Q. bicolor* Willd.)	White Oak	8 stumps
Acer ubrum L.	Red Maple	1 stump
Ulmus (probably *U. americana* L.)	Elm	1 root, 1 stem
Cephalanthus occidentalis L.	Buttonbush	1 root, 1 stem

* These are the oldest plant remains found in the site. The oak and red maple stumps were rooted in place and represent vegetation preceding the formation of the lower peat (Fig. 14).

was not excessively wet. In a saturated soil the root systems of these trees presumably would not have developed as profusely, nor to such depths, in the relatively impervious clay. In this connection it is significant that studies of root penetration in *Spartina* salt marshes indicate that the overwhelming majority of roots are concentrated in the upper six or eight inches of the muck soil, and exceedingly few roots penetrate below 12 inches.[4] Similarly, in *Salicornia* marshes, the bulk of the roots are in the upper two or three inches. In view of such measurements, limited as they are, there seems no reasonable doubt that the tree roots and herbaceous roots observed in strata below the peat layer represent vegetation covering the area *before* development of true marsh or reed swamp conditions. Additional evidence of a distinct change in ecologic conditions between the time of the oak woodland and the *Phragmites* swamp (peat formation) stage may be observed in the relation of the stumps to the peat layer (Fig. 14). The fibrous layers of peat invariably lie *above* the soil surface on which the trees grew, and it seems clear that the change in water relations which brought about development of the reed swamp (*Phragmites*) caused the death of the trees, and, *ipso facto*, the preservation of the stumps in the peaty mass which accumulated around them. Furthermore, careful study of the stumps and their state of preservation leads to the conclusion that peat formation around them must have been quite rapid. The inner heartwood of the larger oak stumps was in sound condition and virtually unmodified, as shown by microchemical and anatomical study. The outer portions of the stumps, on the other hand, were degraded and "humified" with abundant evidence of degradation by fungi (Plate V, 2 and 3). The roots showed no evidence of attack by fungi, and presumably were decomposed under anaerobic conditions. Their physical condition was quite comparable to that of the weir stakes. The tops of the stumps projected into the marine silt overlying the peat, and in one case numerous marine borer holes were found on the uppermost parts. The obvious conclusion to be drawn from these facts is that the stumps persisted throughout the entire period of deposition of 8-12 inches of peat without undergoing *excessive* rotting and were sufficiently intact at the time of the marine invasion to support the development of marine borers. *It is probable, therefore, that the total Lower Peat accumulation represents a period of time to be measured in decades rather than centuries.* This consideration is of the greatest significance in efforts to date the deposit by stratigraphic correlation of its contained pollen.

[4] Chapman, 1938.

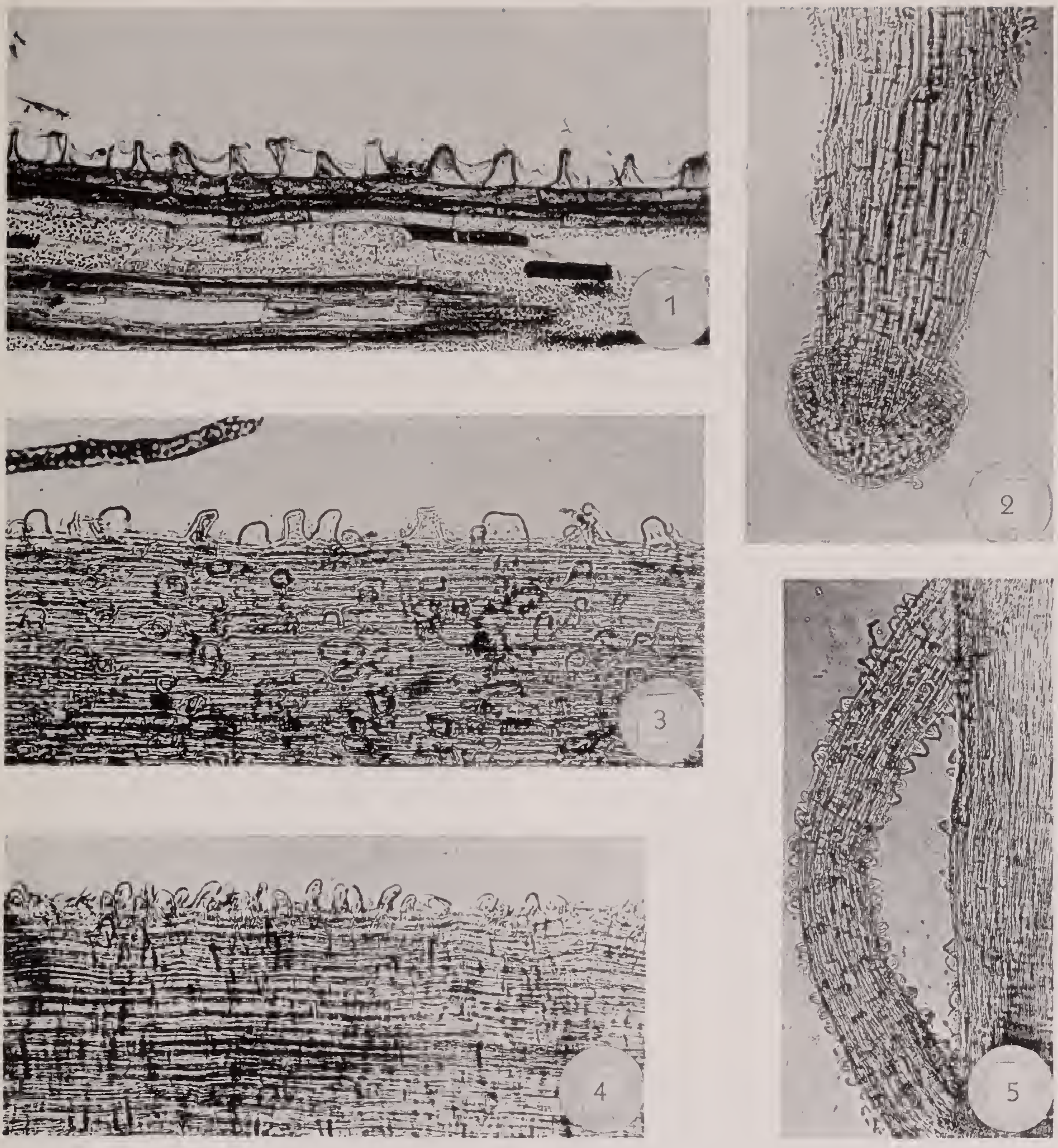


PLATE IV

Root Remains in the Lower Peat

1. Longitudinal section of root of living *Scirpus cyperinus* for comparison with roots isolated from the Lower Peat. Note distinctive epidermal cells (idioblasts) which represent the epidermis. X 167.
2. Root tip from Lower Peat, showing structural preservation of delicate epidermal tissues, including the root cap. X 167.
3. Root epidermis from lower peat probably referable to the genus *Scirpus*. Development of similar epidermal structures of the roots throughout the Cyperaceae and several other families of the monocotyledons makes exact generic identification virtually impossible. X 167.
4. Root epidermis from the lower peat showing the type of idioblast cells common among the Cyperaceae. X 167.
5. Root and rootlet of living *Scirpus acutus* showing the prevailing pyramidal shape of the idioblast cells in this species. Contrast with 3, and 4. X 84.

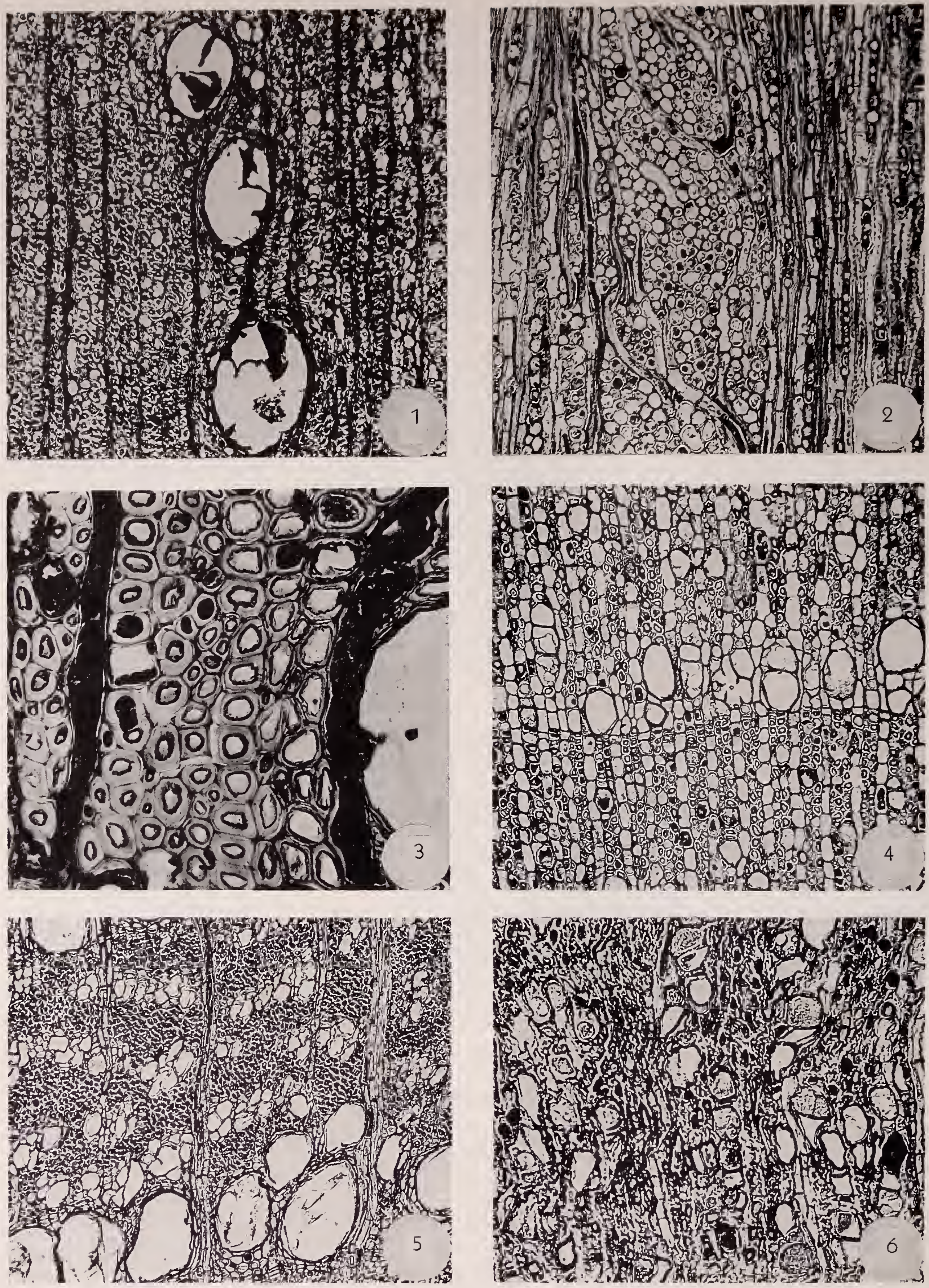


PLATE V

(See opposite page for explanation.)

The Lower Peat

The general relations of the Lower Peat layer in the Boston Basin have been described by Johnson[5] and by Judson in the present study. In all exposures of this peat layer observed and studied by the writer, the lowermost portions are "amorphous" in texture, the central and major portions fibrous, and the upper portions "silty" and "amorphous". Fibrous layers are frequently absent or poorly developed. The upper and lower portions often grade imperceptibly into contiguous strata, whether these be the underlying clay or sand, or the overlying marine silt. The three zones or layers differ greatly in mineral content, botanical composition and in their mode of formation, although they possess a deceptively uniform superficial aspect.

Since the peat constitutes a focus of botanical interest in the site, with the notable exception of the Fishweir itself, detailed study was made of the deposit and its identifiable plant remains. The methods utilized were somewhat diverse and required perfection of techniques for anatomical study of such fragmentary remains. A detailed analysis of the peat as an organic deposit, and its plant constituents in particular, possess many points of interest, more particularly in view of the general paucity of information on the anatomy of plant remains in peat.

Three procedures were followed in study of the Lower Peat: 1. Deflocculation and separation of gross fragments; 2. Microtome sectioning; 3. Chemical analysis and microbiological study.

[5] Johnson, et al, 1942.

PLATE V

Trees and Shrubs from the Lower Peat and the Fishweir.

1. Transverse section of root of white oak stump found *in situ* at base of the Lower Peat. The root was collected from a level 4 feet below the base of the stump where it had penetrated in joints of the underlying massive blue clay. The woody tissues show advanced degradation. X 85.
2. Tangential longitudinal section of heartwood from the outer part of the white oak stump showing advanced degradation of the woody tissues. Compare with 3. X 85.
3. Transverse section of hard inner portion of the same stump shown in 2. In the inner parts of the large stump the woody tissues show only incipient stages of cell wall degradation despite their prolonged exposure to similar environmental conditions producing the changes indicated in figures 1 and 2. X 255.
4. Transverse section of stem of *Cephalanthus occidentalis* (Button bush). Both roots and stems of *Cephalanthus* were recovered from the basal portions of the Lower Peat. X 85.
5. Transverse section of branch wood of *Ulmus* sp. from base of Lower Peat. X 60.
6. Transverse section of stem wood of *Ilex glabra*. This specimen consisted of a small branch forming a wattle of the Fishweir. X 128.

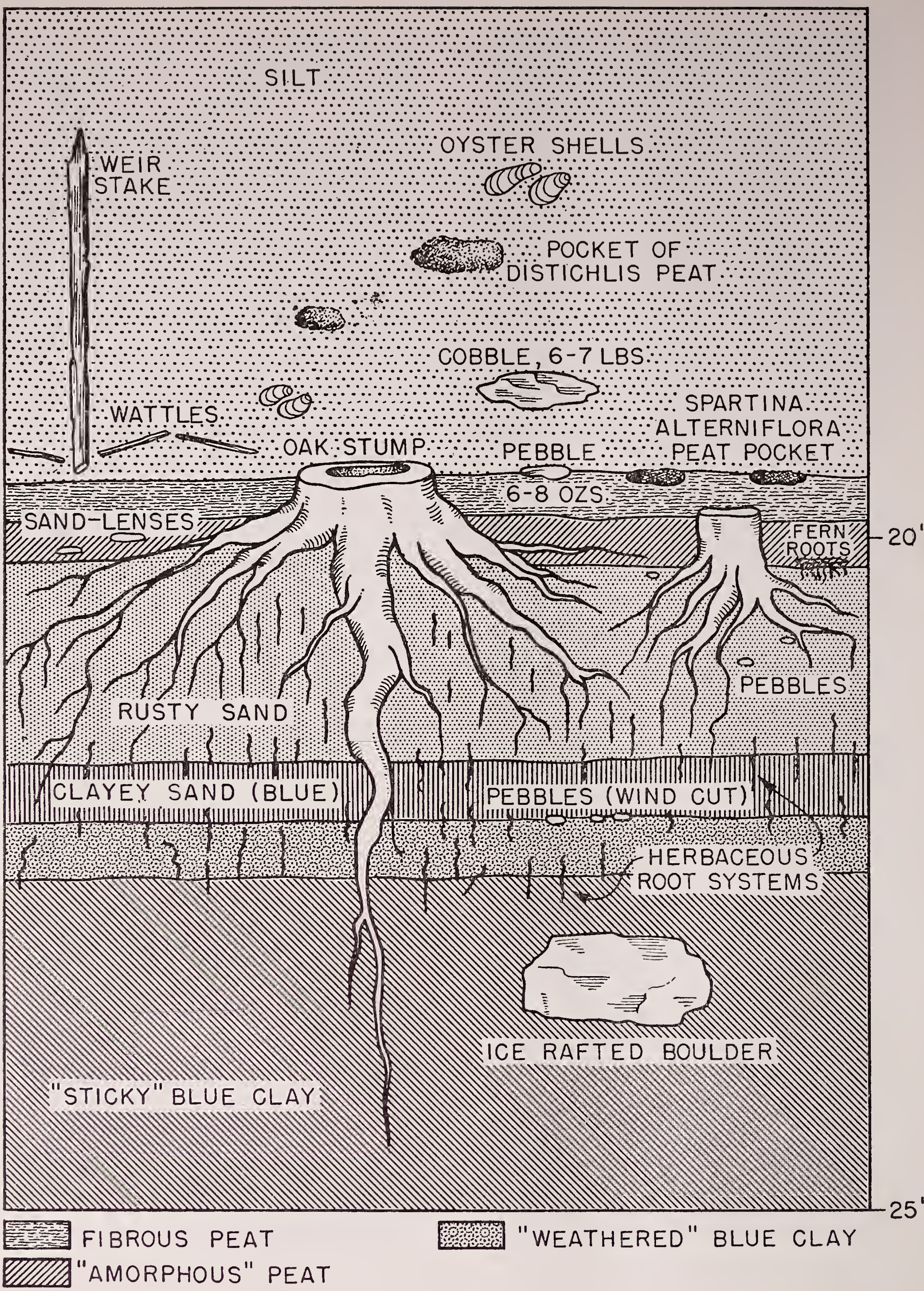


Fig. 14. Diagram to Show Relation of Oak Stumps to Surrounding Deposits.
Ed. Note: The top of the right hand stump should have been drawn above the Fibrous Peat. Unfortunately the error was not noted until too late for correction.

1. For purposes of identification of the plant constituents, representative samples of the deposit were collected in the building excavation, including several complete cores removed from vertical exposures of the thicker more fibrous sections. In addition to collections from the Stuart Street site, a large core of peat secured in 1939 in the Boylston Street excavation was re-examined for comparison.

Several means were utilized for the separation of the peat remains. After considerable experimentation, the following procedure was found to be quite satisfactory as well as adaptable to the varied physical properties of the peat:

a) Small quantities of the moist peat were swollen and partially deflocculated by immersion in 5-10 per cent. aqueous potassium hydroxide for 6 to 24 hours at room temperature. The softened mass was carefully broken apart to accelerate subsequent treatments.

b) The residues were washed by successively decanting to remove soluble "humic" substances and excess alkali. At this stage, many large fragments of rhizomes, roots, and root systems could be removed.

c) The peat mass was flooded with lactic acid (85 per cent.) and gently agitated. With acidification, the plant tissues became lighter in color and discrete parts were readily distinguishable. Fragments of roots, seeds, and other plant parts were easily selected with the aid of a dissecting microscope and forceps. The physical properties of the viscous lactic acid solution facilitated dissection of the matted peat mass under the microscope.

If it is desirable to bleach plant residues further in preparing them for identification of permanent reference, sodium chlorite proves unusually satisfactory.[6] After chlorinating and decolorizing in acid sodium chlorite solution, delicate cellulosic and cuticular residues are obtained which exhibit clearly details of the epidermis and frequently of the underlying tissues. Experience has shown that the underground parts of many herbaceous peat-forming plants are in an excellent state of preservation in peats whereas their aerial parts are highly degraded, and indeed, frequently absent. This is undoubtedly due to the fact that roots and rhizomes which enter the environment of a peat in the living condition are not subjected to the extensive aerobic decomposition which occurs on the surface of a marsh or bog. Many of the roots removed from fibrous peat show root hairs and similar delicate structures in an almost perfect state of structural preservation (Plate III, 1;

[6] Barghoorn, 1948.

Plate IV, 2, 3, 4). Meristematic tissue of the root apices is often quite well preserved and occasionally structurally intact as shown in Plate II, 2; Plate III, 4. Such striking contrasts in the degree of preservation of tissues demonstrate that a distinction should be made between degradational processes which occur *in peats* and those which occur *on the surface* of a peat-forming layer. They suggest, in addition, the need for further study of the relative role of aerobic and anaerobic microorganisms in relation to peat formation.

In order to identify the plant remains comprising the bulk of the fibrous Lower Peat, characteristic epidermal and cuticular structures of the roots and rhizomes were examined. Comparisons were made with similar parts of a wide range of swamp, marsh, or aquatic plants. Material for comparison was secured from herbarium sheets or from plants collected in the field. A total of two hundred species of monocotyledonous and dicotyledonous herbaceous plants were examined, representing nearly all genera encountered in marshy or wet habitats in the northeastern United States. Roots or rhizomes from herbarium specimens were prepared for anatomical study and permanent reference by clearing in caustic soda, followed by dilute lactic acid. The cleared tissues were mounted in glycerin or glycerin jelly.

The lowest portions of the Lower Peat were found to be devoid of identifiable plant fragments. The organic matter is finely divided and highly degraded. Occasional roots which had grown down from the overlying peat-forming vegetation run vertically through it. The amorphous lowermost layers grade imperceptibly into the thick fibrous layers above. In the transition zone, plant fragments are larger and better preserved. There is a decrease upward in the amount of inorganic matter, and an increase in the concentration of pollen grains, fungus hyphae and spores. Fern spores similarly gradually increase in frequency. In the transition from "amorphous" to fibrous peat, however, the most striking feature is the sudden preponderance of *Phragmites* and various genera of the Cyperaceae (Table V). Concurrently, roots of ferns become fairly common and well-preserved sporangia of ferns are frequent. In the upper parts of the fibrous peat, roots and rhizomes of *Phragmites, Scirpus, Juncus,* and various members of the Cyperaceae, particularly *Carex,* comprise the bulk of the larger plant fragments. The matted root systems of these plants are clear evidence of an autochthonous accumulation of a fresh-water reed-marsh vegetation. The presence of fern roots *in situ* and frequently well preserved sporangia are evidence of predominantly fresh-water rather than brackish conditions.

The *Phragmites—Scirpus—Juncus—Carex* stage of peat formation apparently persisted over large portions of the area until it was terminated by the sudden invasion of marine waters. The upper portions of the fibrous peat

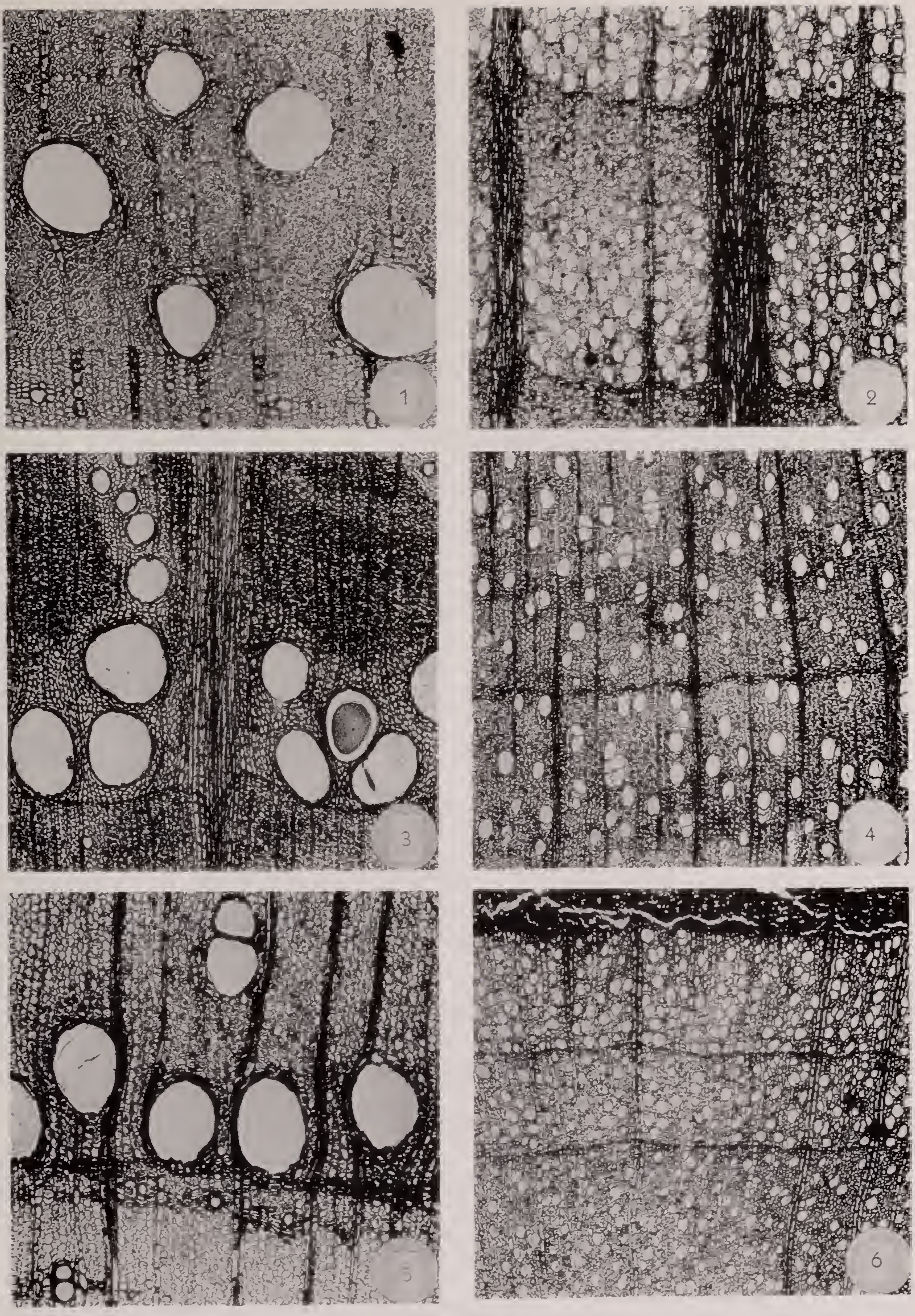


Plate VI

Stakes and Wattles from the Fishweir

1. Transverse section of stake showing hickory structure. X 85.
2. Transverse section of stake showing beech structure. X 55.
3. Transverse section of stake showing red-black oak structure. X 55.
4. Transverse section of stake showing hard maple structure. X 55.
5. Transverse section of stake showing ash structure. X 85.
6. Transverse section of wattle showing wood structure of the bayberry type. X 55.

Plate VII

(See opposite page for explanation.)

TABLE V. GENERA AND SPECIES OF PLANTS REPRESENTED IN THE LOWER PEAT*

Scientific Name	Common Name	Part of Plant Preserved
Scirpus sp.	Rush	culms and roots
Phragmites communis Trin.	Tall Reed	rhizomes and roots
Cladium mariscoides (Muhl.) Torr.	Reed	roots
Carex sp.	Sedge	roots
Juncus sp.	Rush	roots
Spartina alterniflora Lois.	Salt Marsh grass	rhizomes and roots
Dryopteris?	Marsh fern	roots
Smilax sp.	Cat Briar	seeds
Cephalanthus occidentalis L.	Button bush	fruit

* Excluding pollen grains and spores of lower vascular plants.

PLATE VII

Degradation of the Cell Wall

Figures 1 to 6 inclusive are from selected portions of a white pine stump found in the silt layers above the Fishweir.

1. Transverse section showing differential degradation of certain cells in the late wood. Note certain intact cell walls, others incipiently degraded and many cells in which the secondary wall is highly degraded. X 70.
2. Tangential longitudinal section of degraded tissue of the late wood. The dark, heavily stained amorphous material consists chiefly of the degraded remains of the central and inner layers of the secondary wall. X 105.
3. Tangential longitudinal section of the outermost portion of the late wood of an annual ring, showing the presence of a few relatively undegraded cell walls surrounded by the greatly degraded cells. Compare with figure 1. X 105.
4. Transverse section showing incipient degradation of the secondary wall of an isolated tracheid surrounded by tracheids in which the secondary walls have been highly degraded. X 175.
5. Transverse section showing structural residue of the wood resulting from differential degradation of diverse portions of the cell wall. The visibly intact walls, represented by cell wall outlines, consist of the middle lamella separating adjacent cells plus the primary wall and outermost secondary wall of each bordering cell. The amorphous mass in the center of each cell consists of the degraded remnants (lignin residue in large part) of the central and innermost portions of the cell wall. The intact cell outlines are therefore 5 layered residues as indicated more diagrammatically in Plate VIII figures 1, 3, and 6. X 525.
6. Transverse section similar to that shown in 5 but more highly magnified. Note the discrete outline of the coagulated remnants of the secondary wall in the center of each cell lumen. X 910.

show an abrupt transition to silty peat (not to be confused with the overlying marine silt) of very different microscopic as well as gross structure. The contact zone between fibrous and silty peat is frequently featured by minute lenses of sand, probably indicating a subaqueous erosional interruption between the layers. Roots, rhizomes, and occasional culms of *Spartina alterniflora* occur in the uppermost portions of the *Phragmites—Carex* peat, indicating a probably rapid conversion of the area into salt marsh. The silty peat grades almost imperceptibly into marine silt above, indicating no pause in the transformation of deposits to a marine or estuarine phase lasting through until the final formation of the Upper Peat in fairly recent times.

2. An interesting addition to ecological interpretations of the Lower Peat was obtained by study of thin sections of the peat. For this purpose several fresh samples of the most fibrous peat were selected and cut into small blocks, one to two centimeters thick. In order to retain the diatom shells in the peat matrix the blocks were slowly dehydrated without demineralization or other pretreatment, and subsequently embedded in paraffin. After embedding, the excess paraffin was trimmed away and the peat exposed. The blocks were then soaked in water for 8 to 10 days. Thin sections were prepared by use of a sliding microtome. By this procedure it was possible to secure sections 10 – 15 μ in thickness. The presence of minute mineral particles and silicious diatom tests caused considerable difficulty in sectioning, but did not render the method impractical for histological study of the plant remains.

Microscopic examination of thin sections of the peat show that the organic components consist chiefly of highly degraded, compressed plant residues. Interspersed among these are occasional tissues or plant parts remarkably well preserved and relatively uncompressed. It may be inferred, therefore, that the laminated, compressed nature of the peat is not due solely to pressure of the overburden, but due as well to degradation of the plant remains at the time they entered into the peat mass (compare Plate II, 1 and 2, Plate II, 4). The abundance of fungus spores and hyphae throughout the peat demonstrate that considerable aerobic degradation of the plant tissues occurred on the peat-forming surface; hence the marsh was probably seasonally dry. Diatom shells of the elongated type are most frequently found with their long axes oriented parallel to the parting planes of the peat, and probably indicate periodic transport and deposition during flooding of the marsh.

Many of the plant tissues of the peat exhibit a considerable degree of "coalification" as evidenced by their appearance in thin section. A surprisingly large number of discrete fragments show gradational changes between distinct cellular organization and the amber colored "amorphous" residues which are characteristically abundant in more highly "coalified" organic

Table VI. Hydrogen Sulfide Content of the Lower Peat

	Silty, Sedimentary Peat	Highly Organic Phragmites Peat
Weight of fresh peat in grams	1905.0	2419.0
Water content, in grams	1172.0	1264.5
Total Solids, in percent (oven dry)	37.7	26.2
H_2S content, grams	0.016	0.017
H_2S content in ml. at STP	10.6	11.2
H_2S content calculated per liter of water in the peat: ml. under STP (calculated)	9.04	8.80

Table VII. Chemical Analysis of Dried Peat, Nonmetallic Elements

Highly organic *Phragmites*-sedge peat	
Nitrogen, % of dry wt.	2.16
Chloride, % of dry wt.	3.59
Phosphorus, % of dry wt.	0.21
Sulfur, total % of dry wt.	3.71
Sulfur (in ash)	0.95*
Water content of fresh sample, %	73.80
Total solids in fresh sample, % (calc.)	26.20

* Some of the organic sulfur may have been fixed in ashing and appeared in the ash.

residues. It should be emphasized, however, that the "coalified" residues of the peat are probably not comparable chemically to similar "polymerized" residues in true coals inasmuch as they exhibit far less resistance to oxidative chemical treatments such as chlorination and bromination.

There is no evidence of mineralization of the peat by either calcium carbonate or silica. At the base of the lowermost peat layers, however, and in many of the roots which penetrate the underlying clay, minute crystals of pyrite are quite common. In occasional specimens of larger roots in the clay, the center of each root was found to be partially filled with a geode-like development of pyrite crystals.

3. Chemical analyses of the major organic and inorganic constituents of the peat and of the peat ash were obtained. In addition, several rough quantitative measurements were made of the amount of hydrogen sulfide in the fresh peat. Results of these analyses are presented in Tables VI, VII, and VIII.[7]

[7] Hydrogen sulfide determinations were made by the author. Quantitative analyses shown in Tables VII and VIII were made by Dr. H. C. Parish of Skinner and Sherman, Inc., 246 Stuart Street, Boston, Massachusetts.

Plate VIII

Degradation of the Cell Wall.

Figures 1-3, 5-8, are from 5μ sections taken from selected portions of a white pine stump found in the silt layers above the Lower Peat.

1. Transverse section showing the structural residue of the cell walls of degraded wood after extraction of amorphous residues and "humic" substances by treatment with sodium chlorite. The cell walls which appear visibly intact consist of the intercellular substance separating adjacent cells plus the primary wall and *outermost* secondary wall of each bordering cell. The amorphous mass representing the degraded central and inner layer of the secondary wall has been removed by the chlorination treatment (compare with Plate VII figure 5). Note the distinct overarching borders of the bordered pits indicating clearly that the bulk of the structural residue consists of the outermost layers of the secondary wall. Stained with Ruthenium red. X 910.
2. Transverse section similar to that shown in 1 but showing in contrast the preservation of the secondary walls of four tracheids. The secondary walls of these cells are clearly delimited internally by the innermost formed layer of the secondary wall. Sections delignified by sodium chlorite treatment and stained with Ruthenium red. X 525.
3. Transverse section, delignified, showing a structural residue consisting of the primary walls and the outermost layers of the secondary wall. Note the torus of the pit membrane in a bordered pit. To the left a tracheid may be seen in which the central and inner layers of the cell wall are retained. Stained with Ruthenium red. X 910.
4. Transverse section of a spruce tracheid showing the various layers of the cell wall which comprise the structure of a bordered pit. Note that the major portion of the border comprises the central layers of the secondary wall. Compare with figure 1 showing a structural residue in which the pit "border" consists solely of the innermost portion of secondary wall. X 910.
5. Transverse section showing incipient degradation of the innermost secondary walls of tracheids which exhibit compression wood or "rotholz" structure. The heavily stained portions of the wall between the degraded inner lamellae and the primary wall are noncellulosic layers of the secondary wall. Section undelignified, stained with safranin and Haidenhains haematoxylon. X 525.
6. Transverse section showing structural residue consisting solely of intercellular substance, primary and outermost secondary cell walls. The bulk of the degraded cell wall (lignin residue) extracted by sodium chlorite. X 525.
7. Tangential longitudinal section of a late wood tracheid showing the structural residue of a bordered pit represented only by the primary pit membrane (torus) and the primary and outermost secondary cell wall. Compare with figures 1, 3, and 6. Undelignified, stained with Haidenhains haematoxylon and safranin. X 525.
8. Transverse longitudinal section similar to that shown in Plate VII figure 1. Treated with 72% H_2SO_4 to swell the cellulosic residue of the secondary wall. Incomplete swelling reaction attests to the degraded condition of the structural residues of the primary and outer secondary wall residues, although these residues are visibly intact as shown in figures 1, 2 and 6. X 833.

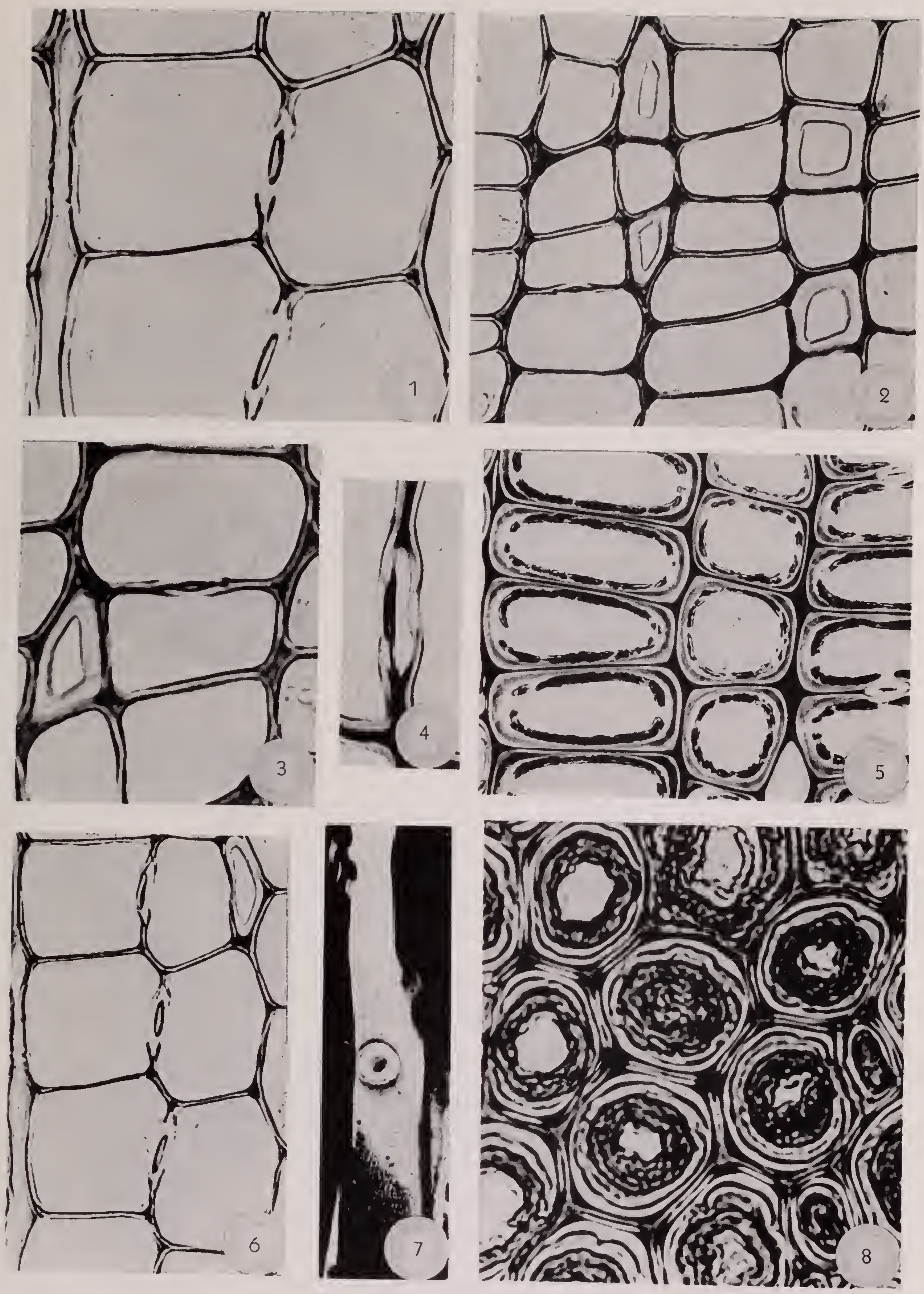
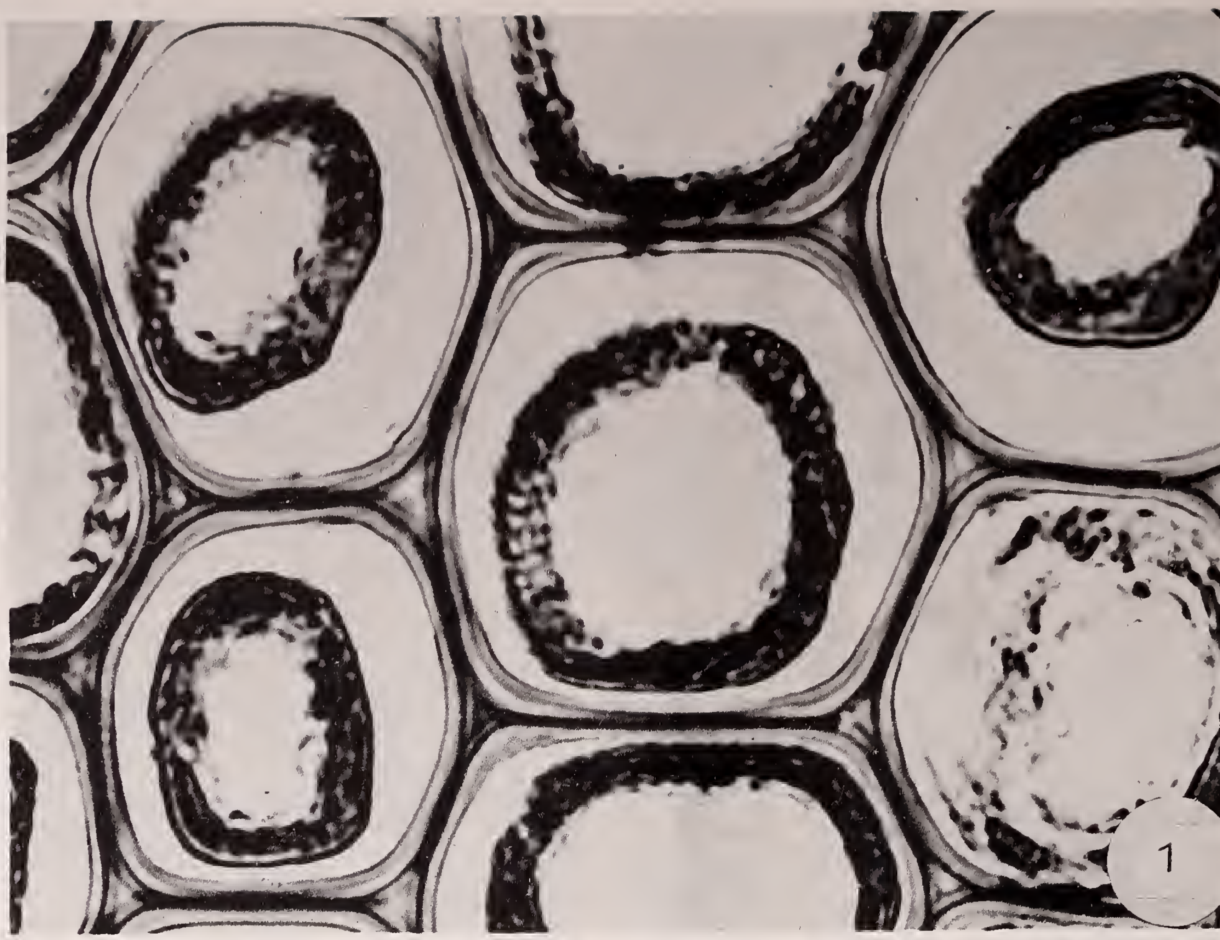


Plate VIII

(See opposite page for explanation.)



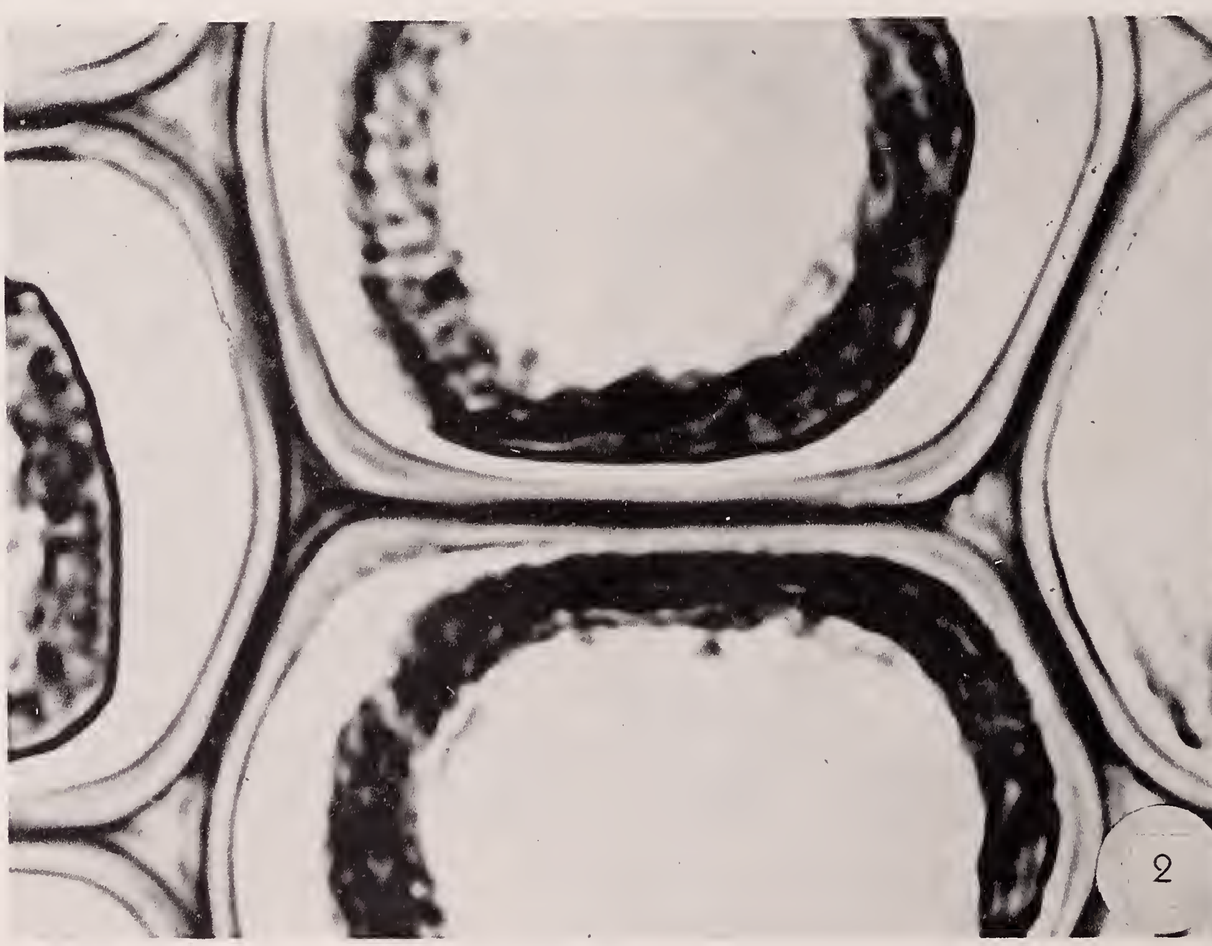


PLATE IX

(See opposite page for explanation.)

The presence of a considerable amount of hydrogen sulfide in the peat layers was evident throughout the course of excavation in the lower levels of the site. It therefore became of interest to determine in some way the approximate amount of free hydrogen sulfide, since the abundance of this gas might have direct bearing on the decomposition processes in the peat. It is also of much interest to know whether hydrogen sulfide is at present being evolved by bacterial activity or whether its abundance in the peat is due to occlusion and retention of the gas beneath overlying sediments.

For purposes of determining the amount of hydrogen sulfide in the peat two large samples were collected from freshly exposed layers and placed immediately in rubber-stoppered 4-liter Erlenmeyer flasks. Within a few hours after collection, the flasks and contained peat were heated to boiling temperature for approximately an hour. The resulting gases were passed through a series of condensing bottles and the hydrogen sulfide precipitated as cadmium sulfide from a neutral solution of cadmium chloride. Approximately a liter of water, slightly acidified with lactic acid, was added to the peat before boiling. The cadmium sulfide precipitate was difficult to filter and a very small amount was lost in filtration. The amount of hydrogen sulfide was calculated from the precipitate; summary of the calculations are shown in Table VI. The results obtained by this method are probably not highly accurate, since there are a number of variables in the procedure. However, they provide approximate quantitative data which are of considerable significance in visualizing the chemical environment of the peat. The amount of hydrogen sulfide present in the free water of the peat is far from the theoretical saturation point, but is nevertheless surprisingly high. If the figure of 9.0 ml. hydrogen sulfide per liter of water in the peat is even approximately correct, it is obvious that very large amounts of this gas are present in the deposit as a whole. The effect of free hydrogen sulfide on the degradation of cellulose and other plant

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PLATE IX

Degradation of the Secondary Wall

1. Transverse section of white pine, showing diagrammatically the degradation of the secondary wall. The visibly intact layers of the cell wall consist of the intercellular substance, primary wall and outer secondary wall. Note the shrunken residues of the central and innermost secondary cell walls in the lumen of each cell. Undelignified, stained with Ruthenium red. X 1200.
2. Transverse section similar to that shown in figure 1 except more highly magnified. Note the discrete boundaries of the visibly intact borders of the outermost secondary walls of the two tracheids. The inner granular residue consists of the degraded central and inner lamellae of the secondary wall. Undelignified, stained with Ruthenium red. X 2100.

tissues in organic deposits is virtually unknown as far as the author has been able to determine. It is highly probable, however, that the prolonged presence of even small concentrations of this gas and its aqueous solution (hydrosulfuric acid) might bring about chemical hydrolysis of cellulose. The fact that many woody samples removed from the deposit show (under high magnification) virtually identical degradational changes regardless of surrounding matrix (clay, peat, or silt) strongly supports the theory that a significant part of the decomposition of the wood has been largely chemical and not microbiological. Of the various chemical agents affecting woody remains in diverse levels of the site, hydrogen sulfide is one which is universally present.

For purposes of determining whether hydrogen sulfide is still forming in degradation of the peat and wood, various anaerobic sterile media were inoculated under carefully controlled conditions with fresh samples of the fibrous peat. Inoculations were made in the laboratory with fragments selected from the center of large masses of freshly collected peat. The inocula were therefore free from contamination as well as the influence of atmospheric oxygen until the moment of inoculation.

It is a well-recognized fact that the bulk of the hydrogen sulfide produced in marine and brackish sediments is released by the activities of bacteria which reduce sulfates of the sea water to hydrogen sulfide utilizing in these processes

TABLE VIII. CHEMICAL ANALYSIS OF THE ASH OF SELECTED PEAT SAMPLES

	Scirpus Peat Boylston St. Site (1939*)	Sedimentary Peat (highly mineral) North Central Area of Excavation	*Phragmites — Scirpus — Carex* Peat. Central Area of Excavation
1. Loss on ignition %	3.20	2.80	20.70
2. Silica as SiO_2%	61.40	70.80	33.60
3. Iron oxide Fe_2O_3%	13.89	4.31	10.14
4. Aluminum oxide Al_2O_3%	8.11	6.49	6.86
5. Calcium oxide CaO%	1.12	1.68	3.92
6. Magnesium oxide MgO%	4.42	4.89	7.02
7. Sodium oxide Na_2O_3%	0.89	2.88	10.85
8. Potassium oxide K_2O%	0.74	1.55	0.62
Mineral matter in % dry wt. (ash, after combustion)	44.2	80.1	26.0
Organic matter in % dry wt.	55.8	19.9	74.0
Water content of original sample %	—	—	73.8

* Samples stored for 8 years in preservative solution, hence the data for sodium and potassium are probably meaningless due to solvent extraction.

a wide range of carbohydrates as energy sources. Comprehensive studies of the physiology of sulfate-reducing bacteria have resulted in the development of satisfactory media and techniques for the cultivation of these organisms in enrichment cultures.[8] Following these methods, a series of media were prepared in glass-stoppered bottles according to the procedure of Van Niel for the preparation of liquid anaerobic cultures.[9] Various carbohydrates were supplied as energy sources for sulfate reduction, viz.: cellulose (cotton, filter paper and thin sections of wood), glucose, and sodium lactate. Control bottles of identical media were prepared in order to test the capacity of the media for supporting the growth of sulfate-reducing bacteria. An additional series of mineral salts-cellulose media were prepared for the purpose of determining the presence or absence of anaerobic cellulose digesting bacteria.

The results of microbiological study indicate *complete absence of sulfate-reducing bacteria* in the Lower Peat. Without exception, all the test bottles inoculated with fragments of peat failed to show the development of sulfate-reducing bacteria (*Sporovibrio*) during a period of observation of over two years. The *same bottles of media, as long as two years after their preparation, have shown vigorous development of sulfate-reducing bacteria within 24-36 hours after their inoculation with freshly collected marine sediments from estuarine deposits.* Moreover, identical media have invariably shown positive reactions when inoculated in the field with fragments from submerged peats collected in deposits periodically exposed at low tide along the west shore of Cape Cod. The presence of sulfate-reducing bacteria is immediately evidenced in such cultures by the precipitation of black iron sulfide resulting from reaction of the released hydrogen sulfide on traces of ferrous ammonium sulfate in the medium.

Additional evidence pointing to apparent sterility of the Lower Peat was secured by efforts to culture bacteria from freshly collected samples of wood from the deposit. Dr. Herman Sweet, of Tufts College, kindly offered to test such material by inoculating a varied series of media and incubating them under anaerobic conditions. A dozen media containing diverse energy sources, both carbohydrate and protein, were inoculated with freshly exposed fragments of wood. In no case was there evidence of bacterial growth.[10]

Numerous liquid anaerobic mineral salts-cellulose media yielded negative results after inoculation with freshly collected fragments of the Lower Peat, although control samples of the same media yielded vigorous cultures of gas-forming anaerobes upon inoculation with fresh marine sediments or with raw marine peats.

[8] Baars, 1930; Van Delden 1904. [9] Van Niel, 1931.
[10] Communication from Dr. Herman Sweet.

On the basis of these experimental studies, although they are of limited scope, there is no conclusive evidence of current bacterial activity in the peat strata nor in plant tissues (i.e., stakes and wattles) introduced into these strata long after their deposition.

Considerations such as the foregoing raise the fundamental question of the relative role of microorganisms and of chemical processes in the alteration of plant remains in organic sediments. It is evident that peat accumulation measured in terms of the ecology of marsh vegetation is fundamentally under the influence of microorganisms which operate both aerobically and anaerobically. In deposits such as these, which often form the classical conception of "peat," it is probable that a major portion of the source vegetation is aerobically degraded and "humified" before it actually enters the deposit. However, it does not follow that all chemical changes which occur during the early stages of chemical alteration and "coalification" of plant remains in a wide range of sediments are caused by living organisms. The structurally

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Plate X

Sections of Modern Piling, Fishweir Stakes and Other Woods.

1. Transverse section of a sample from a spruce pile driven into the Back Bay sediments about 1848. Section from the outermost portion of the pile indicating decomposition similar to that shown in figures 4 and 5 Plate VII. Undelignified section, stained with haematoxylon and safranin. X 525.
2. Transverse section of hard pine. The wood was exposed to the sea and the action of marine fungi. Fungous attack on the cell wall is concentrated in the central layers of the secondary wall, in a manner similar to the hydrolytic degradation shown in sections of degraded wood from the Fishweir site. X 525.
3. Transverse section of spruce piling, same specimen shown in figure 1. Section from the outermost rings of the pile showing various stages in the incipient degradation of the secondary wall. X 525.
4. Transverse section of a silicified fossil wood (*Taxodium*) of Tertiary age showing degradation prior to silicification. Degradation of the secondary walls appears strikingly similar to that in unmineralized woods from the Fishweir site, as shown in Plate VIII fig. 5, and Plate IX 1 and 2. Ground section. X 525.
5. Transverse section, Fishweir stake showing dogwood structure (cf. *Cornus florida*). This section, typifying the stakes in general, shows decompositional changes similar to those shown in woods of more recent age, figs. 1–3 as well as in woods of much greater age, figs. 4 and 6. Comparison of the structural residues of the Fishweir stakes, with those preserved in silicified woods, indicates that similar stages in degradation of the cell wall preceded mineralization. X 875.
6. Transverse section of an unidentified fossil wood of Cretaceous age. This wood is an intensely silicified organic residue of the original woody tissue, the organic portion of which closely resembles cellular residues of the Fishweir woods (fig. 5). X 833.

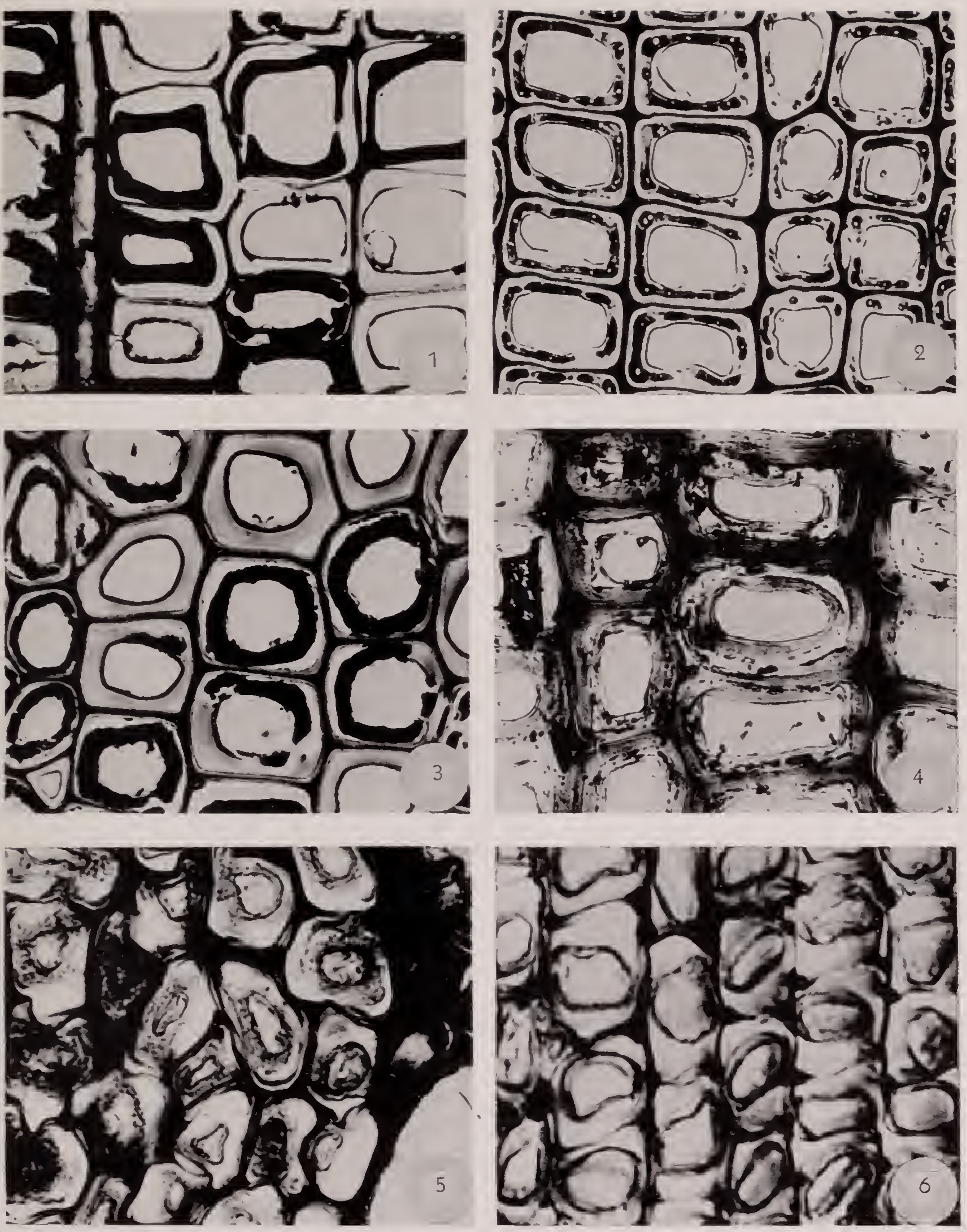

Plate X

(See opposite page for explanation.)

preserved remains of land plants which document the history of vegetation from the Paleozoic to the present indicate the fallacy of simple generalizations concerning the fate of plant remains in organic sediments. It may be argued that chemical changes induced by the presence of hydrogen sulfide or other by-products of microorganisms are basically microbiological in origin. This

TABLE IX. GENERA AND SPECIES OF TREES AND SHRUBS REPRESENTED IN THE SILT LAYER ABOVE THE FISHWEIR AND LOWER PEAT*

Scientific Name	Common Name	Number and Type of Specimen
Tilia americana L.	Basswood	1 stem fragment
Amelanchier canadensis (L.) Medic	Shadbush	1 branch
Larix laricina (Du Roi) Koch	Larch	1 charred stick
Pinus Strobus L.	White Pine	1 stump

* These represent drifted fragments.

unquestionably is true, but it is likewise evident that many chemical changes in plant tissues during degradation are not under *direct* control of microorganisms. Such considerations are of great theoretical significance in drawing meaningful distinctions between the so-called biochemical and the so-called dynamo-chemical processes in coal formation, of which "peat" is the earliest stage.[11] Many further critical investigations of peats from the combined histological, microchemical and microbiological point of view are essential to settle these basic questions. It is obvious that simple microbiological sampling of peat bogs cannot supply critical information, since it is necessary to analyze a wide range of organic accumulations of diverse geological age with a view to both microbiological processes and the histological changes which occur in plant tissues during the earlier stages of "coalification".

In an effort to secure supplementary evidence concerning environmental conditions during formation of the peat, chemical analyses of the Lower Peat and determinations of its mineral content were made. A limited but significant amount of data correlating source vegetation and the mineral-organic ratios in resultant peats has been determined through studies of Pearsall and others.[12] It is of interest to compare such organic and inorganic analyses of peats of known plant source and ecological conditions with organic and inorganic analyses of the Back Bay peat. Data summarizing these analyses of the Lower Peat are included in Tables VII and VIII.

[11] White, Thiessen and Davis, 1913.

The organic content of the Lower Peat, in its contrasting phases, may be compared with the organic component of the following types of peat from marshes in the British Isles:[12]

Dominant Vegetation	Average Organic Content
1. *Typha latifolia* consocies	34.0 per cent.
2. *Scirpus – Phragmites* association	40.7 per cent.
3. *Equisetum fluviatile* consocies	60.9 per cent.
4. *Carex* association	89.4 per cent.

In the more mineral peat from the Fishweir site (Table VIII) it is evident that the organic content is less than that of any of the four types of peat listed above. It is probable, therefore, that this "peat" is essentially an organic silt largely allochthonous in origin and composed primarily of transported mineral matter. The fibrous organic peat, on the other hand, is intermediate between the *Scirpus – Phragmites* and the *Carex* peats (*Equisetum fluviatile* is not a significant member of eastern American peat-forming associations).

Study of the identifiable plant remains and other heterogeneous constituents of the Lower Peat support, in general, various ecological interpretations which may be deduced from correlating mineral – organic ratios with the source vegetation. Thus, the more fibrous, more highly organic portions of the Lower Peat show abundance of *Phragmites* and *Carex* and correspondingly less *Scirpus*. The low percentage of inorganic materials in the fibrous peat indicates its autochthonous development and relative freedom from water-transported sediments. Peat from the Boylston Street site, on the other hand, shows dominance of *Scirpus*, less *Carex* and *Phragmites* and a correspondingly lower organic content. The latter peat undoubtedly formed in a wetter phase of the marsh and possesses concomitantly a higher percentage of transported material. The highly mineral "peat" (Table VIII) contained relatively few identifiable gross plant fragments, a large amount of detrital material, and abundant comparatively coarse mineral fragments. These characteristics indicate a predominantly alluvial origin.

It is apparent from these analyses of the Lower Peat as a sediment that wide variation in the environmental conditions of deposition prevailed in close proximity. This is attested both by considerable fluctuation in plant populations preserved in the peat, and in widely ranging mineral-organic ratios and distinct differences in mineral composition of the ash (Table VIII). Accordingly, the entire area, between and including the two building excavations, in pre-Fishweir time was probably a poorly-drained marsh

[12] See Tansley, 1939.

with scattered areas of deeper water, representing drainage channels, and with isolated or interconnected areas of reed-swamp and sedge-meadow. In general, portions of the area closer to the ancestral Charles River (Boylston Street site) were probably occupied by the more aquatic phases of the vegetation; those further south, by reed-swamp and wet meadow. Local areas of highly mineral peat probably represent drainage channels and their resulting strata of alluvial deposits. In comparable areas of moderate sedimentation in the Esthwaite marshes of England, it has been shown that similar zonation occurs according to the following sequence:[13]

Carex ⟶	*Phragmites* ⟶	*Scirpus*
(Drier)	(Wetter)	(Open Water)

increasing mineral content

In connection with these comparisons it is significant that reed-swamp (*Phragmites*) development takes place only on stable or sheltered substrata and not on loose gravels or stony surfaces. If the gravels or sands are stabilized, *Phragmites* spreads, usually on a substratum of 30 to 60 per cent. organic matter. *Scirpus*, on the other hand, often occurs in more exposed positions and in deeper waters. Its structure and habit of growth render it more resistant to wave action than *Phragmites*, and the seeds of many species of *Scirpus* are capable of germination under water.[14]

The major portion of the Lower Peat is clearly a fresh-water accumulation. Probably the basin in which it formed was periodically affected by brackish invasions from the Charles River estuary. A *gradual* transition to salt marsh conditions probably did not occur as shown by the sharp unconformity between fibrous *Phragmites* peat containing fern remains and the isolated areas of overlying coarsely fibrous *Spartina alterniflora* peat. The latter developed directly over the fresh-water sediments, and its unconformable relation to the fibrous peat is strikingly shown by the occasional presence of *Spartina* roots and rhizomes, vertically oriented through the horizontally compressed *Phragmites* peat. The *Spartina* phase was apparently of brief duration, and rapidly gave way in the Fishweir basin to marine or estuarine silt, the lower levels of which contain abundant allochthonous masses of high-tide peat (*Distichlis spicata*), presumably derived by erosion and transport from adjacent hinterlands undergoing headward erosion in the submerging estuary.

Chemical analysis of the fibrous *Phragmites* peat shows the presence of a rather high percentage of nitrogen and a surprisingly large amount of sul-

[13] Pearsall, 1918. [14] Tansley, 1939.

fur in organic combination (Table VII). Quantitative analysis of the ash from this same peat is shown in Table VIII, where it may be compared with ash analyses of two other samples from the deposit. The mineral content of the Lower Peat in general is more like that of "low moor" than of "high moor" peats. A striking feature shown by the analyses is very wide variation in mineral composition of samples from the same deposit collected within a relatively short distance of each other. Such divergences are harmonious with other lines of evidence pointing to local complexities of the depositing area as a whole.

Detailed paleobotanical studies of the Lower Peat have yielded no further clues concerning the age of the deposit, nor of the overlying Fishweir. They have shown, however, that fluctuating zones of vegetation in the area have been featured by increasingly wetter environments, first of a fresh-water phase, finally of brackish and marine conditions. They have also shown that the transition from fresh-water peat to marine peat was rapid, probably resulting from a major topographic change in the development of the submerging Charles River estuary. By inference, in comparing degradational changes in the Fishweir wood with remains of wood in the peat and the silt, it is probable that the Fishweir itself was a structure of relatively short duration. The physical condition of the stakes and wattles, their type of degradation and lack of "humification" indicate that the structure was rapidly silted over and encased in sediments, the extensive accumulation of which ultimately lead to abandonment of the area by the aboriginal weir builders.

PART II

ANATOMICAL AND MICROCHEMICAL STUDIES OF THE DEGRADATION OF PLANT REMAINS FROM THE SITE WITH REFERENCE TO "FOSSILIZATION".

One of the most significant processes which operates in nature is the alteration of plant residues into the economically important substances variously known as peat, lignite and coal. In the course of this investigation it became apparent that the Fishweir and various plant remains associated with it are of unusual interest in delineating very early stages in the long and complex series of events which ultimately result in the "coalification" of plant tissues. Paucity of knowledge in this unsatisfactorily investigated phase of paleobotanical and botanical research has stimulated study of

degradation of the plant remains in the strata associated with the Fishweir.

In order to orient the significance of structures observed in degraded plant tissues it is desirable to note certain fundamental aspects of the structure of the plant cell wall. In higher plants, the presence of a cell wall is the most conspicuous visible feature in the organization of tissues, organs, and, in general, the entire plant body. The cell wall is composed initially of an outermost layer, the *primary wall*, a cellulosic "pellicle" which increases in surface area and varies in thickness during growth and cell enlargement.[15] After enlargement of the cell has ceased a *secondary wall* is frequently formed, always internal to the primary wall. In cells in which secondary walls are not formed, the primary cell wall may become thick and conspicuous. In woody plant tissues, however, thick secondary walls are developed internal to the primary walls and the major topographic feature of such tissues consists of the enormously thickened secondary wall. Structural relations of the various lamellae of the plant cell wall have been lucidly demonstrated by Bailey in an extensive series of studies.[16]

In normal, unaltered woody tissue, the secondary walls of cells consist primarily of cellulose, with lignin (and other substances) interpolated in intimate physical relation within the cellulosic framework.[17] Owing to its chemical structure and the physical aggregation of its molecules, cellulose exhibits a brilliant birefringence when observed in polarized light, i.e., between crossed Nicol prisms, except when oriented in positions of extinction. Chemically, cellulose in its native state in the cell wall undergoes drastic swelling (and ultimately hydrolysis) when treated with strong mineral acids (such as 72 per cent. sulphuric acid, 40 per cent. hydrochloric acid, etc.). The lignin component of the cell wall, on the other hand, shows a lack of birefringence when viewed in polarized light, negative reaction to strong mineral acids, but a pronounced reaction and solubilization when treated with various oxidizing agents, particularly halogen compounds.

In a previous detailed microscopic study of the stakes and wattles from the Fishweir it was shown that these woods were highly modified, both physically and chemically, although retaining to a great extent their structural pattern.[18] Wood of the hardwood stakes was shown to possess a highly modified birefringence, varying from feeble to scarcely detectable. Secondary walls of the cells showed various stages of disintegration into an isotropic granular residue. In almost all cases, however, the tenuous outer layers of the secondary wall retained their form and their capacity for feeble birefringence. A general sequence of deteriorative changes seemed to be indicated;

[15] Bailey, 1938. [16] Bailey, 1935; 1938; 1940.
[17] Freudenberg, 1932. [18] Bailey and Barghoorn, 1942.

a sequence in which the order of degradation of the secondary wall appeared to be: (*a*) the central layers, (*b*) the innermost layers and (*c*) the outermost or first formed layers. The primary walls and the true intercellular substance were visibly unmodified. Microchemical tests indicated that the birefringent residues were truly cellulosic, but that the bulk of the "wood" consisted of a lignin "residue". Chemical analyses, however, demonstrated that the cellulosic fraction of the stakes consisted of highly degraded cellulose.[19] Residues of lignin remaining after breakdown of the cellulosic fractions of the wall were found to be apparently unmodified chemically.

The absence of "humified" residues in the stakes and wattles, and the fact that the wood was uniformly degraded, physically and chemically, provided a reasonable basis for concluding that conspicuous changes in the wood were due primarily to a gradual hydrolysis and degradation of the cellulosic matrix of the cell wall.

Reinvestigation of the Fishweir woods (Plate VI) and the extension of comparable study to a wide range of other plant remains supports these earlier conclusions. A far more complete sequence of deteriorative changes has been observed, however, by selecting, in addition to the stakes and wattles, woody remains from numerous levels of the deposit. The structural and chemical changes appear to represent fundamental phenomena in "fossilization" and merit careful analysis.

In discussing the degradation of plant tissues in nature, it is essential that reasonable distinction be made between deposits in which aerobic microbiological changes may proceed at a rapid rate on the surface of the accumulating layers, and sub-aqueous deposits in which environmental conditions involve deeper submergence and a physical environment which is virtually anaerobic. So fundamental is this distinction that the character of the ultimate sediments is greatly influenced if not determined by the degree of these contrasting conditions of deposition and subsequent change. It might almost be said that at one extreme of the spectrum of organic decay are the various processes which operate in the soil, particularly in soil organic matter, and, at the other extreme, conditions of deep fresh-water lakes and the sea. In all cases, microbiological processes probably induce physical and chemical changes in plant tissues incorporated in the substratum, but the degree of change and the duration of these processes vary tremendously.

It is obvious from even a cursory microscopic examination of the plant fragments from fibrous or woody peats that simple generalizations can scarcely be made regarding the mode or the extent of breakdown of the plant

[19] Jahn & Harlow, 1942.

remains as a whole. Certain tissues show almost complete reduction to "amorphous" residues, others, a marked alteration in form and cellular organization, and still others, striking preservation of structure. Such varying degrees of preservation and breakdown are indicated in Plates II and III, showing the physical organization of plant fragments from the Lower Peat. In the aggregate, and by chemical analysis of gross samples of peat, it has been shown by numerous studies, that certain categories of compounds in the original plant tissues are degraded more rapidly than others. For example, with increasing depth (i.e. age) the percentage of hemicelluoses and of cellulose declines, while the percentage of lignin and lignin-like substances increases.[20] A continuation of this change in the quantitative relations between the two major categories of plant substance characterizes "humification" and subsequent "coalification", i.e. conversion of peat to brown coal, lignite and higher rank coals.

That the ultimate loss of cellulose in plant remains may be greatly retarded, however, for many millions of years is readily demonstrated by examination of fossil woods of varying geological age. Lignitized woods ranging in age from Cretaceous to Pleistocene have been investigated by the author by means of chlorination techniques in conjunction with anatomical study. In all cases a structural residue, often exceedingly tenuous, of extensively degraded cellulose has been found. Frequently the secondary walls of isolated cells and occasionally groups of cells exhibit *visibly* intact (though chemically degraded) structure. Interestingly enough, the cellulosic structural residues of lignites possess a remarkable resemblance to those of wood from peat deposits. Structural and chemical change in the degradation of plant remains under anaerobic conditions therefore shows a significant correlation with fundamental anatomical features of the originally unmodified cell wall.

If cellulose is a chemical entity and of uniform chemical composition (although not necessarily of uniform physical organization) in plant cell walls it is remarkable that its disappearance during deterioration is not relatively consistent throughout the entire cell wall. The fact that the cellulosic lamellae are not uniformly degraded despite long exposure to conditions of degradation points to possible chemical differences, rather than merely to differences in physical state, or protection by encrusting substances such as lignin, phenolic compounds, or terpenes.

In deflocculated and subsequently delignified ("dehumified") samples of the Lower Peat innumerable delicate plant fragments may be extracted. The larger fragments consist for the most part of cuticular and epidermal

[20] Waksman and Stevens, 1928; 1929.

cellulosic residues of monocotyledonous roots and rhizomes. Microscopic examination reveals the frequent structural preservation of even the most delicate epidermal structures such as root hairs, root cap cells and the distinctive "idioblast" cells of cyperaceous roots. (Plate III, 1; Plate IV, 2, 4). Although these tenuous residues of roots have retained their minute anatomical features, there is a striking absence in the same organs of thick-walled fibrous or conductive tissues. Absence of internal mechanical or conducting tissue may be demonstrated by observing the roots or rhizomes in different planes of focus. In *undelignified preparations of comparable residues,* degraded remnants of the originally lignified conducting tissue and thick walled fibers may be observed. Their thick secondary walls, frequently heavily lignified, have been reduced to virtually amorphous residues which are readily extracted by chlorination in acidified sodium chlorite solutions. *Anatomically therefore, the structural residues preserved in the peat consist for the most part of thick, previously unlignified primary walls.* Thick, lignified secondary walls have meanwhile undergone very extensive degradation, even though exposed to identical environmental conditions of deterioration. That the structurally intact cellular residues are actually highly modified chemically may be determined by microchemical tests and by conspicuous changes in their physical properties. *However, it is a paradox of note that the most delicate tissues of various plant organs may be far more resistant to conditions of anaerobic degradation than are cells or tissues possessing thick, frequently heavily lignified, secondary walls.* It seems difficult to interpret such selective degradation of cellulose in different portions of the plant cell wall except in terms of fundamental chemical differences in the cellulose of successively formed lamellae of the cell wall.

That pronounced differences in the rate of cellulose degradation are not isolated phenomena in peat formation is clearly shown by microscopic study of wood removed from various levels of the Back Bay sediments. A large drifted log of white pine provided an unusually complete series of stages in the degradation of coniferous wood. The log was embedded in silt at a level above the upper portions of the Fishweir stakes. A series of radial strips was secured from the log and small samples removed from these for anatomical and micro-chemical study. The outer portions of the entire log were quite uniformly softened, the inner parts quite hard. A graded sequence of increasing hardness was found between the peripheral soft layers and the inner hard portion.

Thin sections of selected samples were prepared by embedding small blocks in paraffin, without pre-treatment, and sectioning on a sliding microtome. With care it was possible to secure 5μ sections from even the harder and less

degraded samples. Owing to the degraded nature of the cellulose residues and their adherence to the surface of glass slides, it was feasible to treat and stain thin sections of the wood according to standard histological procedures.

Progressive stages in the degradation of the secondary wall are illustrated in Plate VII, 1-6. Three outstanding features may be noted in these thin sections of degraded wood: (1) reduction of the major portion of the cell wall to a granular, virtually amorphous residue, (2) retention of a structurally intact cell wall residue or "membrane" corresponding in position to the primary wall, and (3) the presence of isolated or contiguous goups of cells whose secondary walls are relatively unaltered.

It is evident that the bulk of the granular amorphous residue is derived from the secondary wall whose cellulosic fraction has undergone virtually complete degradation, releasing the interpolated lignin residue. That this is in fact a lignin residue is evidenced by its total extraction during delignification treatment (Plate VIII, 1, 2, 3 and 6).

The anatomical and chemical significance of structurally intact wall layers in the degraded wood is of great interest. The thin intact "membrane" varies in thickness in different parts of the growth ring as shown by comparison of Plate VII, 5, 6 with Plate VIII, 1, 2. Existence of cellulose in the structurally preserved, often excessively thin, wall or "membrane" is indicated by its distinct birefringence in the microscope when viewed between crossed Nicols. Birefringence is greatly accentuated by delignification. Such birefringence of the "membrane" might be interpreted as an indication of the primary wall residues of adjacent cells, separated by true middle lamellae, even though the extent of the layers is excessive. It may be shown, however, that the structurally intact "membranes" actually constitute a *five layered* structure comprising the primary walls of contiguous cells and the outermost layer of their secondary walls. This is evident from a careful study of the relation of the structure of the "membrane" to the bordered pits. It is apparent (Plate VIII, 1, 3, 6) that the structual "membrane" (accentuated as a delignified cellulose residue) enters into the formation of the innermost portions of the pit border (Plate VIII, 1). Inasmuch as the pit border is solely a feature of the secondary wall, it is clear that the "membrane" actually consists in large part of the outermost layer of the secondary wall. The portion of the "membrane" consisting of secondary wall is essentially a very minor portion of the original unmodified secondary wall as indicated by examination of sections in which cells possessing intact secondary walls are intermingled with cells possessing degraded secondary walls (Plate VII, 1, 4, and Plate VIII, 2, 3).

It should be emphasized that the outermost portions of the secondary wall exhibit very different staining reactions, optical properties, and physical be-

havior from those of the broad central and inner layers of the secondary wall. This fundamental difference in chemical and physical properties is significantly related to pronounced differences in resistance of the respective lamellae to degradation. In other words, if features revealed by thin sections of the degraded wood are interpreted in terms of cell wall structure it is difficult to escape the conclusion that basic chemical differences must exist between the first-formed layers of the secondary wall and the later-formed layers of the central and inner portions of the secondary wall. The first-formed or outermost lamellae of the true secondary wall, it is seen, behaves in a way strikingly similar to that of the primary wall. The primary wall and the outermost tenuous (occasionally thickened [Plate IX]) layer of the secondary wall therefore consitute a structural residue persisting after virtually complete degradation of the major portion of the secondary wall.

The relation of such phenomena in the degradation of wood to those in peat formation are quite harmonious. The majority of *structurally preserved* plant remains in fibrous sedimentary peats are composed of the primary walls of herbaceous plants. In woody and coarsely fibrous peats, the plant remains often reveal varying amounts of residues of the secondary wall. A comparable condition is frequently found in plant residues of far greater antiquity, including lignites of Tertiary age, in which coherent cellulosic structural residues of wood may be revealed by means of careful delignification.

It is evident that chemical changes in the degradation of plant remains, whether due largely or only in part to microbial activity are not simple, uniformly diffused chemical modifications of the plant constituents. Various fractions of the original constituents are selectively attacked, broken down or actually released, i.e. solubilized. The fate of various chemical entities (or groups of chemically related substances) can scarcely be established by mass quantitative measurements unless these determinations are coördinated with anatomical study of the tissues themselves. In the case of cellulose of the woody cell wall, it is obvious that anaerobic degradation is featured by a selective breakdown of certain lamellae at a far more rapid rate than others. Fundamental differences in the rate or degree of degradation of the layers are apparently not due solely to intensity of lignification or protection by encrusting substances. Intense lignification or saturation with resins, however, may greatly retard cellulose degradation, whether it is induced by microorganisms or by simple chemical hydrolysis (*vide* the resistance of resin-saturated knots or branches of the hard pines).

In order to determine further the physical state of the cellulosic residues in the Fishweir wood, measurements were made of the viscosity of their solutions in cuprammonium. For this purpose samples were selected from

the heartwood of clear-grained ash and dogwood stakes. The samples were triturated in a Waring blender, sieved to pass 40-80 mesh, extracted with alcohol, benzene, and ether, and subsequently delignified by the use of alternate treatment with mildly acidified sodium chlorite, and aqueous ammonia. Comparable samples were prepared from fresh sound heartwood

TABLE X. VISCOSITY IN CUPRAMMONIUM SOLUTION.
COMPARISON OF "HOLOCELLULOSE" OF THE FISHWEIR STAKES WITH THAT OF NORMAL WOOD.

Source of Sample	Viscosity in Centipoises Average of Two Readings*
1. White Ash, normal wood, delignified in sodium chlorite	74.2
2. Fishweir stake, white ash, delignified in sodium chlorite	17.4
3. Dogwood (*Cornus florida*) normal wood, delignified in sodium chlorite	110.9
4. Fishweir stake, Dogwood. Delignified in sodium chlorite	10.6

* Measurements by Martin Gurley, Esselen Research Corporation, Boston, Massachusetts.

of the same species, likewise delignified. Both the degraded and undegraded holocellulose fractions were dissolved in cuprammonium hydroxide and measurements made of the viscosity of resulting solutions. The measurements secured show a far lower viscosity in the case of the degraded Fishweir wood; on the order of a six to tenfold decrease (Table X).[21] These facts are consistent with other lines of evidence in indicating that the cellulosic residues of the degraded wood are extensively modified chemically, even though structurally preserved.

The significance of sequential stages in alteration of the cell wall is of primary importance in interpreting the fossilization of plant tissues. For example, in many paleobotanical descriptions of structurally preserved plants the unusual preservation of delicate tissues such as terminal meristems and parts of reproductive organs has often been interpreted as indicating rapid mineralization immediately following deposition of the plant fragments. Inasmuch as such tissues are composed essentially of cells with thin primary walls they are truly delicate in the physical sense. The examination of plant remains in peats, however, indicates that such residues are among the chemically more resistant fractions of the original tissues. The presence of

[21]Viscosity determinations were secured through the kindness of Dr. G. J. Esselen, Esselen Research Corporation, Boston, Massachusetts.

relatively uncompressed, structurally intact apical meristem cells in the Lower Peat of the Fishweir site shows that *such structures can persist for periods of thousands of years even though they are unmineralized* (Plate II, 1, 2; Plate III, 1, 4).

Similarly, a study of well-preserved silicified woods of various geological horizons has demonstrated in many cases a remarkable similarity of their organic residues with those from woods of the Fishweir site. Silicified woods not infrequently show extraordinary preservation of original structure. Even though of virtually mineral consistency in gross aspect, thin sections of fossil wood often simulate relatively unmodified wood when viewed in low powers of the microscope. When more highly magnified, however, silicified wood is usually found to consist of degraded cell wall residues exhibiting varying degrees of alteration of the secondary wall. The residues are embedded in hyaline or semi-granular crystalline silica, frequently of extreme transparency. Degraded residues often possess a distinct lamellation such as that shown in Plate X, 6, in which it may be seen that the structural residue is composed largely of cell outlines, rather than cell walls. The cell outlines are essentially those of a type exhibited in the Fishweir stakes and comprise the "membranes" previously described, consisting of primary walls and the outermost layers of secondary walls. In addition, the innermost layer of the secondary wall is occasionally well preserved and is represented by a contracted and irregular ring of organic material in the central portion of each lumen. General similarity of such a structural residue with that shown in Plate X, 3, is apparent. In one case, the wood is from a recent sediment some thousands of years old and the other from a deposit more than one hundred million years old.

It should be noted in connection with such comparisons that intermediate stages in the degradation of the cell wall may be found in both recent and ancient fossil woods. Degraded woods of comparatively recent age may show essentially the same histological aspect (Plate X, 1, 3). In such cases, degradation, whether fundamentally microbiological or largely chemical and hydrolytic, yields a structural residue essentially comparable to that found in older deposits in which the degradational processes have been operating for infinitely greater time.

It is evident from examination of a wide range of structurally preserved plant remains that certain basic changes characterize the anaerobic degradation (and preservation) of plant tissues. Among these characteristic structural changes is preferential degradation of the central and inner layers of the secondary wall and persistence of the outer lamellae immediately contiguous to the primary wall. The peculiar resistance of the cellulosic fractions of the

outer lamellae of secondary walls and the pronounced resistance of primary walls may be regarded as a basic factor in the preservation of plant tissues in various geological horizons. In deposits accumulating in basins of deposition, both marine and fresh-water, retention of the more resistant cellulosic lamellae of the cell wall permits structural preservation of plant tissues in variously modified forms. These structurally preserved plant residues may subsequently undergo mineralization and yet retain their characteristic anatomical features over immense lapses of time. Early stages in this long sequence of events are discernible in the degradation of wood in deposits such as that of the Fishweir site.

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A MICROFOSSIL ANALYSIS OF THE LOWER PEAT AND ASSOCIATED SEDIMENTS AT THE JOHN HANCOCK FISHWEIR SITE

L. R. WILSON

INTRODUCTION

IN 1946 the deposit of buried peat described here, and a portion of an early Indian fishweir were discovered in the excavation for the John Hancock Insurance Building, located on Stuart Street, in Boston. This fishweir and the geological section is in general similar to that described by Johnson[1] from another excavation located several hundred feet northwest, on Boylston Street, in Boston. In the initial collecting from the deposit an eighty-foot core of the sediments was taken, sectioned longitudinally, and submitted to several investigators for study. One quarter of the core was sent to the writer and some of that data is included in this paper. In order to secure additional material and a more detailed selection of the peat, a channel sample of twelve segments through three and one-half feet of the peat and associated sediments was personally collected from the wall of the excavation in December 1946 (Plate XI). It is this section that embodies the major portion of the present paper.

The top of the peat in the channel secton lay nineteen feet below the Boston Base. The overburden consisted of recent fill, and a section of seven or eight feet of marine silt, clay, and a shell layer. The channel sample represents the lower 4 inches of the marine deposit, the organic horizons and 21¾ inches of the underlying sediments. The channel was divided into twelve segments of various thicknesses for detailed study. The section and sample numbers are listed below.

In the microscopic study of the sediments, information concerning the following four questions was sought: (1) the biotic composition (spores, pollen, and associated animal and plant microfossils), (2) an understanding of the paleoecology of the sediments, (3) information concerning the climate during the sedimentation, and (4) information that would lead to the dating of the fishweir construction.

[1] Johnson, et al, 1942.

Sample No.	*Lithology*	*Thickness inches*
12	Silt (gray green)	4
11	Silt (black-amorphous)	1½
10	Peat (black-fibrous, few sand gains)	¼
9	" (black-fibrous)	2
8	" "	2
7	" "	2
6	Peat (black-amorphous)	2
5	Sandy-clay (blue-gray)	1½
4	" " "	3½
3	Sand (gray-green)	2¼
2	" "	14¾
1	Sandy-clay (blue)	2

METHODS

The segments of the channel sample were cut into as nearly block shape as possible and transported to the laboratory in fruit jars. These samples measured approximately one by two inches and varied in length according to the length of the segments. In the laboratory the microscopic samples were prepared from approximately one-fourth of each segment.

Two different methods of preparation were used on the sediments. Those samples consisting of sand or clay were checked for diatoms and sponge spicules. If none were found, the sample was placed in sixty percent hydrofluoric acid for twelve hours, then centrifuged in copper tubes, washed with distilled water, stained wth saffranin Y, diluted with distilled water, centrifuged (in glass tubes), and placed in Cellosolve. Permanent mounts were made, using Diaphane as a medium. This method disposed of sand grains and aided in the concentration of the spores and pollen. Those samples containing diatoms or sponge spicules were subjected to the following modified Erdtman schedule.[2]

1. Rub air dry sample through a 1 mm. mesh screen into a beaker. Particles of rock or organic tissues too large to pass through the screen are discarded.
2. Cover sample with glacial acetic acid, stir and allow to become thoroughly soaked.

[2] Erdtman, 1943.

3. Pass sample through screen again to remove additional detrital material.
4. Centrifuge sample in glass tubes for two minutes. Pour off liquid to remove most of the acetic acid.
5. Cover residue with acetic anhydride and shake thoroughly.
6. Add concentrated sulfuric acid to the sample, a few drops at a time, and stir. Continue adding acid and stirring until all apparent reaction has ceased.
7. Suspend centrifuge tube in a beaker of water. Heat the water to boiling point, stirring the sample several times during the process.
8. Remove centrifuge tube from the boiling water, centrifuge the sample two minutes and pour off liquid.
9. Add distilled water, centrifuge two minutes and pour off liquid.
10. Add distilled water and several drops of alcohol, shake sample, add alcohol until no further foam appears. Centrifuge two minutes and pour off liquid.
11. Add several cubic centimeters of saffranine Y, stir, and allow to stand until the desired staining is achieved.
12. Dilute with distilled water, centrifuge two minutes, and pour off liquid. Repeat until the water is only slightly colored.
13. Add Cellosolve, shake sample thoroughly, centrifuge two minutes, and pour off liquid. Repeat at least once.
14. Add Cellosolve and transfer the sample into a labeled storage vial.
15. Permanent slides are made by placing a drop of thoroughly dispersed material from the storage vial on each slide and allowing it to evaporate almost to dryness. Stir a drop of Diaphane into the sediment, and place a warmed #0 cover glass over the material. The slides should be allowed to rest on a warming table several days before being studied.

The examination of the samples was conducted with a Spencer Compound Binocular Microscope, using 15X occulars, 16, 3, and 1.3 mm. objectives. The slides were scanned with the aid of a calibrated mechanical stage. The number of spores and pollen grains counted for the statistical analysis varied from 150 to 1200. The difference in number was determined by the frequency of the fossils. The percentages in Table XI are based on the total count of fossils per level and the histogram percents (Fig. 15) are based on tree pollen present (Table XII).

TABLE XI. SPORES AND POLLEN OF THE JOHN HANCOCK SITE

Fossils	Sediments and Sample Numbers						
	Marsh Soil	Freshwater Peat		Saltmarsh Peat		Estuary Organic Silt	Marine Silt
	6	7	8	9	10	11	12
Sphagnum					.5		
Filicieae	5.4	11.5	72.0	85.5	53.0	24.1	5.7
Osmunda	2.7			1.5		2.5	1.8
Lycopodium clavatum				.5			
L. obscurum			.5				
Abies	2.7	2.9		.5	1.1	3.6	.6
Picea	11.0	5.1		.5	1.1	1.7	4.5
Pinus	30.0	28.0	4.5	.5	3.9	3.8	16.6
Tsuga		11.0	5.0	1.5	4.4	8.1	11.5
Populus				.5			
Betula		2.9	1.0		.5	1.2	3.8
Ostrya			1.5	.5	.5		
Corylus		.7				.8	
Carpinus					.5		
Quercus	2.7	13.2	5.0	1.5	5.0	3.8	19.8
Fagus					.5	1.2	1.2
Carya		.7			.5	.8	.6
Juglans		.7					
Ulmus					.5		
Acer	8.1	5.9	7.0	2.0	14.5	25.8	10.9
Fraxinus					1.6		
Liriodendron						.4	
Castalia					1.1	1.2	
Amaranthus		1.7			3.9	3.8	1.8
Compositae		3.7			.5	1.2	
Typha	2.7	9.7	1.0				
Gramineae	24.3		.5	3.0	3.9	10.77	13.8
Cyperaceae	5.4		2.0	2.0	1.65	3.87	3.8
Ilex							.6
Alnus	2.7						

DESCRIPTION OF THE SAMPLES

Sample 1: This sample represents two inches of bluish sandy clay that is 22¼ inches below the peaty soil. No diatoms were observed in the test sample, therefore it was subjected to the hydrofluoric acid method for spore and pollen study. The sample proved to be barren of all fossils.

Sample 2: Consists of 14¾ inches of gray-green sand. The hydrofluoric acid treatment produced no spores or pollen, but a few fragmentary plant tissues were observed. None of these were identifiable.

Sample 3: Two and one-fourth inches above Sample 2, which is the top of the gray-green sand stratum. It was treated as a separate sample to determine any difference that might exist in the organic content. More vegetable tissues occurred. Some of these are conifer wood, identified by the presence of bordered pits. The remainder appear to be grass or sedge tissues. A few fungus spores were observed.

TABLE XII. TREE POLLEN OF THE JOHN HANCOCK SITE

Genera	Sediments and Sample Numbers						
	Marsh Soil	Freshwater Peat		Saltmarsh Peat		Estuary Organic Silt	Marine Silt
	6	7	8	9	10	11	12
Abies	5.0	4.1		7.1	2.8	6.7	.8
Picea	20.0	7.2		7.1	12.4	3.3	7.1
Pinus	55.0	39.5	18.7	7.1	10.4	7.6	22.5
Tsuga		15.6	20.8	21.4	11.9	16.1	16.8
Betula		4.1	4.1		1.4	2.5	5.2
Ostrya			6.2	7.1	1.4		
Carpinus					1.4		
Quercus	5.0	18.7	20.8	21.4	12.4	7.6	27.2
Fagus					1.4	2.5	1.7
Carya		1.0			1.4	1.4	.8
Juglans		1.0					
Ulmus					1.4		.8
Populus				?			
Acer	15.0	8.3	29.1	28.5	37.3	51.8	14.9
Fraxinus					4.4		
Liriodendron						.7	
Ilex							.8

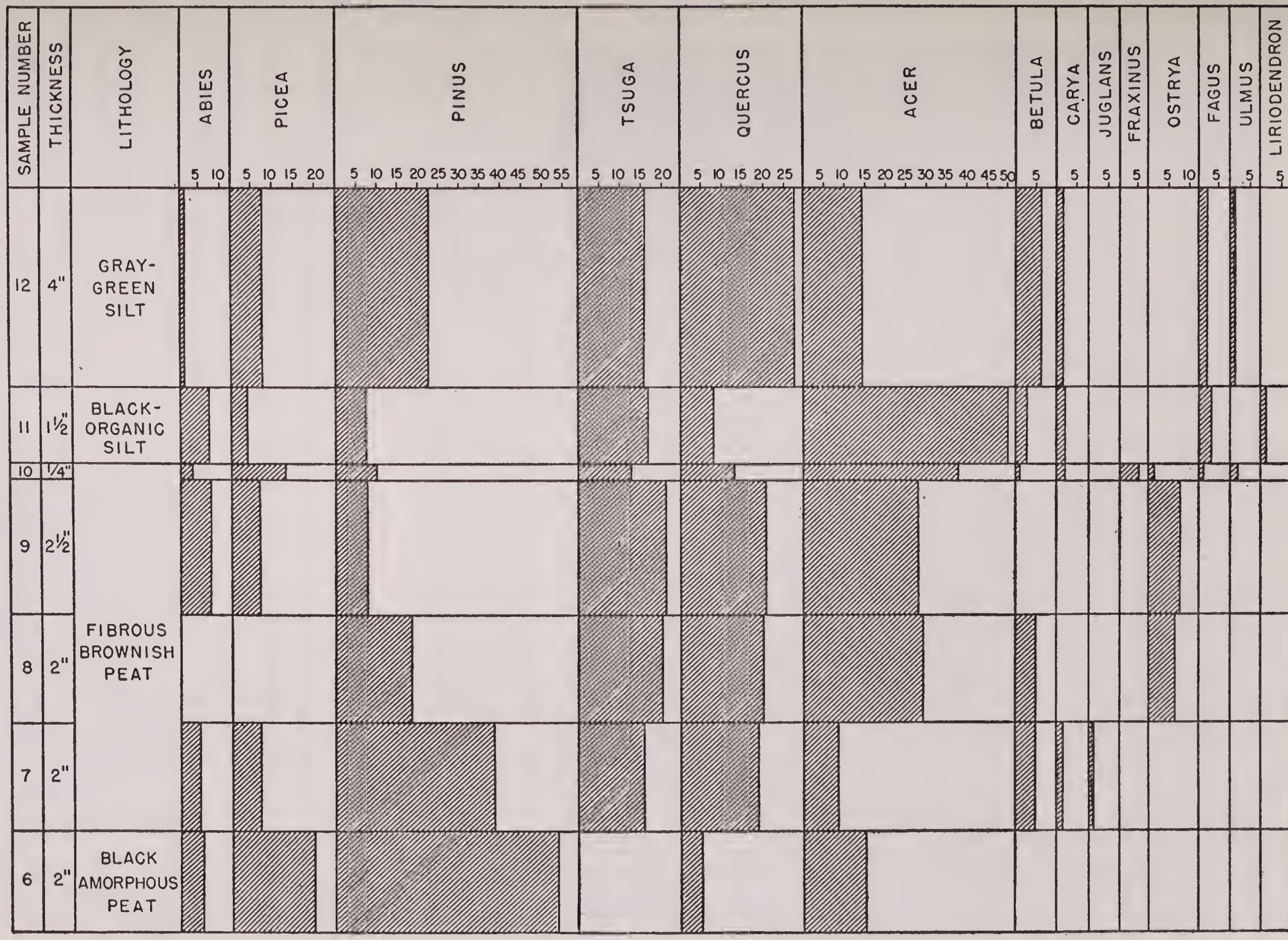

FIG. 15. Histogram of Tree Pollen.

Sample 4: The lower $3\frac{1}{2}$ inches of the blue-gray clay sand was subjected to the hydrofluric acid method. More vegetable tissues occur than in the previous sample and they appear to be of the same type. Fungus spores are also present.

Sample 5: The top of the blue-gray clay sand layer was studied as a $1\frac{1}{2}$-inch sample. It contains the same vegetable tissues and fungus spores as observed in the lower samples. There is a slightly greater abundance of each.

Sample 6: This sample represents the lowest of the organic soils. It is two inches thick, black, amorphous, and under the microscope has the appearance of the peaty soils that are now accumulating at the edge of marshes. The sample was prepared by the acetolysis method. Grass or sedge leaf tissues occur sparsely, while fungal hyphae are abundant. Diatoms are absent and the pollen frequency is very low. As few as ten spores or pollen were found on a single slide. The pollen grains that were found show some evidence of weathering, which would suggest that only those species that have fairly resistant spores or pollen were preserved in quantity. Tables XI and XII give the percentages of spores and pollen in this sample.

Sample 7: The lower contact of the fibrous peat was collected as a 2-inch sample and subjected to the acetolysis method. Grass or sedge leaf tissues are fairly abundant and other plant tissues, possibly of aquatic plants, occur. Diatoms and fresh-water sponge spicules are very abundant. Spores and pollen are abundant and varied as shown in Table XI. This sample has the character of fresh-water peat which accumulates in shallow bays.

Sample 8: This is a 2-inch sample consisting of fibrous peat. Plant tissues of grass or sedge, and probably *Typha*, are common. Diatoms, sponge spicules, and a species of an *Hystrichosphera* are abundant. Spores of ferns and pollen are exceedingly abundant.

Sample 9: Represents $2\frac{1}{2}$ inches of fibrous peat, consisting mostly of grass or sedge tissues. Many fern sporangia and fungal hyphae are also present. Diatoms are not as common as below. Spores and pollen are abundant.

Sample 10: This sample was collected from the top $\frac{1}{4}$ inch of the fibrous peat. It is similar in appearance to Sample 9, but has a small amount of coarse sand grains. The peat contains diatoms, fresh-water sponge spicules and foraminifera. Spores and pollen are abundant and well preserved.

Sample 11: Overlying the fibrous peat are $1\frac{1}{2}$ inches of silty amorphous organic sediment. This stratum was collected as a single sample. The nature of the sediment compares closely with black tidal mud collected from the mouth of the North River, near Norwell, Massachusetts, and the mouth of the Taunton River, near North Fall River, Massachusetts. Few grass or sedge tissues occur in this level. Diatoms, foraminifera, and fresh-water

Plate XI

Exposed section of the John Hancock excavation showing the contact of the top organic silt and the overlying marine sediment. The channel sample described in this paper was collected along the indicated line.

PLATE XII

(See opposite page for explanation.)

sponge spicules are frequent, and fungal hyphae are fairly abundant. Spores and pollen are abundant and varied.

Sample 12: This sample consists of 4 inches of gray-green silt and overlies the black amorphous layer. The sediment resembles a marine silt collected on the sea shore at Rivermoor, Massachusetts. Vegetable tissues are absent, but spores are frequent and pollen is abundant. Many foraminifera and mouthparts of marine worms occur in this level.

PALEOECOLOGY OF THE SEDIMENTS

In order to understand the pollen spectra of the peat and associated sediments, it is necessary to understand the ecology of the sediments. Within the channel sample there is evidence of five types of environment. These may be listed as (1) swamp forest, (2) grass-sedge-cattail swamp and fresh-water pond, (3) salt-marsh, (4) brackish water, possibly an estuary, (5) shallow marine environment.

The black amorphous peat, Sample 6, represents the swamp forest floor. Samples 2 to 5 inclusive, contain plant tissues and spores of fungi. The tissues might represent roots that have been partially decomposed, and the spores may represent soil fungi. If that is true, then the vegetable tissues underlying the black amorphous peat would be genetically related to the swamp forest, since it was on those soils that the forest grew. That the amorphous peat represents a subaerial deposit is suggested by the nature of the sediment. It has the appearance under the microscope of soils collected from a marsh or wet swamp forest floor. That it represents such an environment is borne out by Dr. Barghoorn's discovery (described in this volume) of stumps rooted in a Rusty Sand deposit located a few feet from where the channel sample was collected. The stumps are of oak, and soft maple.

PLATE XII

Microfossils from the John Hancock Excavation

1. *Hystrichosphera*
2. Foraminifera test lining (megalospheric generation)
3. *Sphagnum*
4. Fern spore (Polypodiaceae)
5. *Lycopodium*
6. *Osmunda*
7. *Pinus*
8. *Abies*
9. *Picea*
10. *Tsuga*
11. *Liriodendron*
12. *Castalia*

He also found roots of elm and buttonbush in these soils that would be comparable to those underlying the amorphous peat. The spores and pollen preserved in this level are extremely weathered. Their frequency is very low. In marsh soils, comparatively few spores and grains of pollen are preserved and there appears to be great selectivity of preservation. Pollen grains of pine, spruce, and fir seem to preserve better than most other tree pollen. With this condition at the time of the deposition of the amorphous peat, it is probable that the pollen spectra illustrated in Figure 15 record only those microfossils that preserve in such an environment. It will be noted that hemlock (*Tsuga*) is conspicuously absent. It has a pollen that does not preserve well in marsh soils. It is not reasonable to presume that hemlock was not present in the forest at the time that the amorphous peat was deposited, for the presence of such species as pine, spruce and fir is proof of an affable environment. We must assume that the absence of hemlock pollen is due to lack of preservation of the pollen and not the absence of the species in the region. Dr. Barghoorn has described elm (*Ulmus*) roots from the underlying soils, yet no elm pollen was discovered in the amorphous peat. Again we must assume lack of preservation of the pollen. The presence of oak (*Quercus*) and maple (*Acer*) pollen agrees with the occurrence of the stumps described by Dr. Barghoorn. The maple pollen is that of soft maple rather than hard maple, which also agrees with the identity of the stumps. In addition to the tree pollen, as indicated in Table XII there occur ferns of the Polypodiaceae type and of *Osmunda*. There is also an abundance of grass (Gramineae), some sedge (Cyperaceae), cattail (*Typha*), and alder (*Alnus*) pollen. The presence of cattails, sedges, and some of the grasses indicates a wet environment. Most of these pollen grains may have come from the uppermost portion of the amorphous peat sample and this would suggest that the environment was becoming more moist and suggest further that the swamp soil was being inundated by fresh water.

Overlying the amorphous peat is four inches of brownish black fibrous peat that can be described as a fresh-water deposit. The evidence that it is such a deposit is found in the great abundance of fresh-water diatoms and sponge spicules of the *Spongilla* type. The fibrous nature of the peat suggests that it is the result of grass and sedge accumulation; however, in Table XI the pollen precentages of grass (Gramineae) and Sedge (Cyperaceae) would not indicate an abundance of these plants. The explanation for such low percentages may be found in the preponderance of fern spores of the Polypodiaceae type. The ferns apparently grew upon the grass or sedge mat at the periphery of the pond. Other herbaceous plants represented in this horizon are *Amaranthus*, Compositae, *Lycopodium obscurum*, and

Typha. The last reaches the abundance of 9.5% in Sample 7. In Sample 8 it decreases to 1%. The spores of *Lycopodium obscurum* can be assumed to have been transported by wind from a drier habitat, since this is a forest species which grows almost entirely upon mineral soil. The spores of *Lycopodium* are easily transported by air currents and can be found at some distance from their origin. The tree pollen represented in Samples 7 and 8 is more abundant and varied than in the amorphous layer. Pine, oak, hemlock, maple, spruce, fir, birch, and butternut are the most important pollen constituents in order of their mention in Sample 7. In Sample 8 the order of abundance is maple, oak, hemlock, pine, hornbeam and birch. These two levels probably represent a truer picture of the forest of the region than is indicated in the amorphous layer, since preservation of spores and pollen is more frequent in aquatic peat. The pollen fossils suggest a mixed forest not unlike that of Massachusetts at the present time. In Sample 8 the protozoan belonging to the group *Hystrichosphera* occurs in some abundance. It is a member of a group of animals not well understood and known only in detail from late Tertiary shales. That it should be discovered in this deposit is of considerable interest. Its occurrence here suggests that further work with brackish and near-fresh water deposits will produce valuable results. The specimens observed appear to be all of one species and it is probably new to science. A similar type has been described by Deflandre from the Tertiary of France.[3] The specimens may have come from the uppermost portion of Sample 8 near the contact of the overlying salt-marsh peat.

The next development recorded in the section is a salt marsh. This is recorded by Samples 9 and 10. The peat is brownish black and contains fibrous materials typical of salt-marsh peat. In Sample 9 there occurs the marine diatom *Actinocyclus Ralfsii,* var. *sparsus* as well as the fresh-water diatom, *Pinnularia dactylus.* Fresh-water sponge spicules are also abundant in this level. The presence of these fossils would suggest periodic flooding of the area, probably during high tides and during periods of flood by the Charles River. Fern spores reach their maximum of abundance in Sample 9. These are of *Osmunda,* a wet habitat fern, and probably three species of Polypodiaceae. That they represent ferns growing on the peat is shown by the abundance of fern sporangia in this level. Another herbaceous species of some interest in Sample 9 is *Lycopodium clavatum.* This species may have grown on acid peat near at hand. That habitat is suggested by the presence of *Sphagnum* spores in Sample 10. One might infer that somewhere towards the land a *Sphagnum* moss mat had succeeded over the fresh-water grass

[3] Deflandre, 1947.

peat and that the fresh-water habitat had become sufficiently acid to permit the growth of this moss. Dr. Conger has shown elsewhere in this volume that the diatoms indicate a change in habitat towards an acid water near the top of the peat. The presence of *Sphagnum* and the occurrence of some of the fern spores and the spores of *Lycopodium clavatum* would tend to indicate the same. The tree flora of the region is indicated to be of essentially the same mixed type as during the deposition of the fresh-water peat. Soft maple, oak, hemlock, pine, hornbeam, spruce, and fir are the dominant tree pollen in their order of listing. There is an indication that pine is less abundant at this period than it was at the lower levels. Aspen-like pollen also occurs in Sample 9 but the identity is questionable, though the tree was probably in existence in the plant community suggested by the pollen spectrum. The top of the salt marsh is represented in the peat of Sample 10. In some respects this sample suggests considerable fluctuation between salt and fresh water. There occur fresh-water diatoms, sponge spicules of the *Spongilla* type and pollen of the water lily *Castalia.* A brackish water environment is indicated by the presence of test linings of the meglospheric generation of foraminifera. Fungus spores common in brackish water silt also occur in some abundance. There is a marked decrease in the number of fern spores. *Amaranthus*, Compositae, grass and sedge pollen represent other herbaceous elements. The tree pollen is abundant and more varied than in the levels below. Maple, oak, spruce, hemlock, pine, fir, ash, hickory, beech, birch, hornbeam and ironwood are the important trees in order of their listing.

Above the salt-marsh peat occurs a black amorphous sediment that has the appearance of being an estuary deposit. The lower portion probably represents the disintegration products of the salt-marsh peat. In this deposit are test linings of foraminifera, a great wealth of *Trachelomonas*,[4] and fresh-water sponge spicules of the *Spongilla* and *Heteromeyenia* types. Water lily (*Castalia*) pollen also occurs. The fresh-water elements may have been transported to the place of burial by the Charles River during floods. Spores of ferns show further marked decrease from the salt-marsh peat stage. Grass and sedge pollen increase in abundance as does Compositae pollen. *Amaranthus* pollen is nearly as abundant as in the salt marsh peat. The tree pollen spectrum shows an increase in maple and a decrease in oak, hemlock, pine, and spruce. Birch, beech and tulip tree pollen appear. If the pollen spectrum can be taken to indicate forest succession, the amorphous peat level records the period of greatest mesophytic conditions.

Overlying the amorphous deposit is a marine silt. This is evidenced by the

[4] Deflandre, 1926.

large number of foraminifera fragments, marine *Cladocera* shells and diatoms. The deposit appears to have been laid down in shallow water close to land, for spores and herbaceous pollen are abundant. Grass and sedge pollen is slightly more abundant and *Amaranthus* pollen is present but reduced in number. Fern spores are further reduced in abundance. The tree pollen spectrum shows much less maple pollen but there is an increase in the oak, pine, spruce, and birch pollen. There is an appearance of holly (*Ilex*) and a reappearance of elm. It will be noted that with the possible exception of holly, all of the pollen and spores recorded are wind-borne and are types that may be carried some distance. The fluctuation in the pollen spectrum may be attributed at least partly to the change in sedimentation. Just how much significance can be attributed to this factor must wait further intensive studies. There is a great possibility that the fluctuating shoreline had an effect on the composition of the adjacent forest which contributed pollen to the silts.

COMPARISON OF THE JOHN HANCOCK AND BOYLSTON STREET DEPOSITS

The pollen analysis of the lower peat at the Boylston Street site was made by William S. Benninghoff and that of the overlying silt was made by Arthur S. Knox.[5] The present study agrees in general with those investigations. There are, however, differences in detail that may be attributed to local ecology, or to differences in pollen preservation, resulting from dissimilar sedimentation.

The Boylston Street Lower Peat, as described by Benninghoff, begins with a black amorphous stratum which is overlain by black stratified peat, this evolves into a brown phase, and that in turn is overlain by black peat. This section agrees closely with the John Hancock site. Benninghoff's pollen profile[6] shows in the basal level, the presence of hemlock, aspen, willow, birch, hickory, sycamore, black gum, basswood, Chenopodiaceae-Amaranthaceae, Rosaceae, Plantaginaceae, and Compositae. None of these were found in the amorphous peat of the John Hancock site. This fact might be taken to indicate that the John Hancock amorphous peat was either a drier ground accumulation or that the above pollens were deposited and subsequently destroyed by weathering. Benninghoff did not recognize the presence of fir pollen in the Boylston Street peat in any level. The reason for the omission of that pollen type may be that it was included with the genus *Picea* (spruce), since fir and spruce may be confused, if size alone is used as

[5] Benninghoff, 1942; Knox, 1942. [6] 1942, Fig. 8.

a criterion of identification. Within the stratified black peat and the overlying brown peat there is a general similarity of tree pollen percentage curves except for aspen, willow, and beech which do not occur in the comparable levels of the John Hancock site. In the top black peat level of the Boylston Street deposit a similarity is noted in the increase of spruce, pine, oak, maple, and beech. The herbaceous plant pollen shows several interesting comparisons. Cattail pollen (*Typha*) appears in both black and brown stratified levels and in the top black peat, indicating the presence of such a plant community throughout nearly all the period of deposition. In the John Hancock deposit, this plant community is evident only in the freshwater peat directly above the amorphous layer. A point of marked floristic difference is the comparative scarcity of fern spores in the Boylston Street peat and the remarkable abundance in the John Hancock peat, also the abundance of Chenopodiaceae-Amaranthaceae pollen in the Boylston Street deposit and their scarcity in that of the John Hancock site. These differences appear to be the result of local ecological conditions. The John Hancock spectrum of Amaranthaceae is essentially the same as in the Boylston Street deposit but the abundance is very much less. Benninghoff notes that at least two types of Chenopodiaceae-Amaranthaceae pollen was present and in nearly equal numbers. In the John Hancock deposit but a single species is represented. The lower part of the silt of the Boylston Street site, described by Knox, is stratigraphically the same as that described in the present paper. Most of the same genera of spores and pollen are common to the two deposits. The abundance of pine, hemlock, birch, and elm is nearly the same.

CLIMATIC CONSIDERATIONS

The pollen spectrum (Table XI) indicates by its composition a forest type of mixed elements. One group of species consisting of soft maple, oak, hornbeam, ironwood, ash, elm, and butternut suggests a swamp forest. A second group of species consisting of pine, hemlock, spruce, and fir may represent a forest on slightly higher ground, though this need not necessarily be true. The spruce and fir do, however, represent more northern elements than the others. An examination of the pollen spectrum (Fig. 15) shows a spruce-pine maximum at the base of the section. These two pollen types diminish toward the top of the peat but return again to some abundance in the lower levels of the overlying silt. It has been pointed out above that the amorphous peat at the base of the section contained only those pollen types that appear to withstand weathering to a considerable degree. Such a factor markedly

affects the pollen curves in the spectrum. Whether or not that has actually determined the spectra of pine and spruce, cannot be stated. The gradual decrease in the abundance of pine pollen through the fresh-water and salt-marsh peat would suggest that there was some reduction in the pine population of the local forest. The pollen spectrum of maple, on the other hand, reaches its maximum in the amorphous peat overlying the salt-marsh deposit. Oak reaches its maximum in the marine silt above the amorphous peat. The presence of hickory, ash, hornbeam, beech, elm, and tulip tree in the upper layers of the peat and in the overlying silts suggests a period of more mesophytic environment than at any previous time in the formation of the deposit. Such a statement, however, cannot be made with certainty, since Benninghoff found these same genera at levels comparable to those in which they were absent at the John Hancock site. Therefore it seems probable that local conditions, either of plant distribution or of preservation, are important. This is further borne out by the fact that the fresh-water and salt-marsh peat accumulated in a comparatively short time. Grass and sedge tissues generally produce peat much more rapidly than does moss and wood tissue when the tissues are fairly well decomposed. Therefore, the span of time involved in the formation of the eight inches of peat probably represents not much more than a century. If this is true, the pollen spectrum is more likely to have reflected the local ecological conditions resulting from the fluctuation of water level and marine inundation than climatic change. Another factor that might be effectual in determining the abundance of certain pollen is the amount of weathering a peat horizon undergoes during its accumulation. Those pollen types that are most resistant to decay will become concentrated, and appear as if they were in greater abundance than in less weathered and more rapidly accumulating sediments. Such might be the explanation for the differences in the pollen percents between the basal amorphous peat and the overlying layer. It would seem that the most reliable pollen spectra from which to determine climatic fluctuations are those secured from deposits where similar and uniform sedimentation proceeded over a period of several thousand years. Certainly that is not the case in the Fishweir peat deposit. At best, it seems possible only to state that a short interval of time is represented in the deposit, and that the general assemblage of plant genera and their relative abundance suggest a climate much like that of the present in eastern Massachusetts. Both Benninghoff and Knox, on the basis of pollen spectra, have assigned the age of the Boylston Street deposit to a time more recent than that of the climatic optimum the climax of which may be about B.C. 4200. A similar conclusion is drawn from the pollen spectrum of the John Hancock site.

SUMMARY

1. From a channel sample of three and one-half feet through a buried peat and its associated sediments, five ecological habitats were distinguished by microscopic analysis. These are: (1) a swamp forest or marsh, (2) grass-sedge-cattail swamp and fresh-water pond, (3) salt marsh with periodic brackish and fresh-water floods, (4) an estuary, and (5) a shallow coastal marine bay.

2. The fossil pollen suggests a northern type of mixed forest, consisting principally of pine, hemlock, oak, maple, and beech communities. This assemblage is similar to the present forest of the region.

3. Climatic inference drawn from the pollen spectrum would indicate a climate similar to the present. The fluctuations in the pollen spectrum can in part be explained by differential preservation of pollen in the various types of sediments that were deposited during the five ecological stages.

4. The peat sediments appear to represent a period after the climatic optimum that is estimated to have occurred between 5,000 and 7,000 years ago. The length of time involved in the formation of the fresh-water and salt-marsh peats was probably not much more than a century, since grass-sedge peat is known to form with considerable rapidity.

ACKNOWLEDGEMENTS

The author wishes to express his appreciation to Mr. Frederick Johnson and to Dr. Kirk Bryan for the opportunity to study the John Hancock deposit and for their helpful discussions. He also wishes to express his appreciation to Drs. Elso Barghoorn, Sheldon Judson, and Paul Conger for the opportunity to read their manuscripts which are also published in this volume.

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Plate XIII

Pollen Grains from the John Hancock Excavation.

1. *Fagus*
2. *Juglans*
3. *Carya*
4. *Fraxinus*
5. *Ulmus*
6. *Acer*
7. *Ameranthus*
8. *Ilex*
9. *Quercus*
10. *Carpinus*
11. *Ostrya*
12. *Corylus*
13. *Betula*
14. *Alnus*
15. Compositae
16. *Typha*
17. Cyperaceae
18. Gramineae

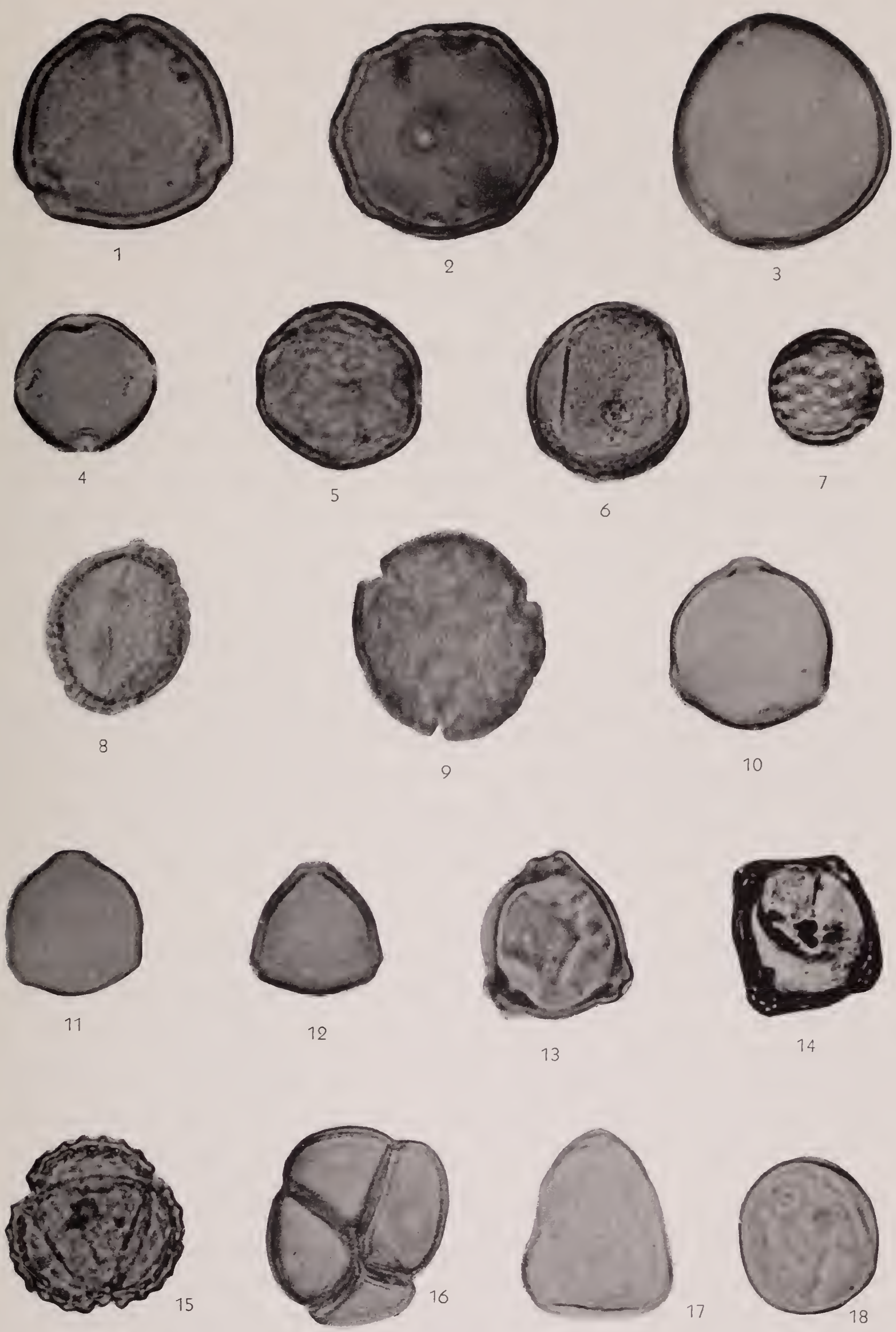

PLATE XIII

(See opposite page for explanation.)

THE FORAMINIFERA

FRED B. PHLEGER

INTRODUCTION

THE Foraminifera have been studied from the long core taken at the John Hancock Building site, and also from samples taken stratigraphically above the core. In addition, several samples of clay from Lynn, Saugus, and Cambridge, Massachusetts, have been searched for Foraminifera. The purposes of this study are: (1) to determine the stratigraphic sequence of the Foraminifera above bedrock at the John Hancock Building site, (2) to determine, if possible, the environment represented by the various faunas in the core, and (3) to determine the environment of deposition of the clays in neighboring areas believed to be correlatives of the lower clay in the present core.

The writer is grateful to Mr. Johnson for the privilege of studying this interesting core. Most of the samples were prepared by Miss Rita Johnson at the Cushman Laboratory for Foraminiferal Research, through the courtesy of Dr. Joseph A. Cushman. Frances L. Parker has checked identification of the species, also at the Cushman Laboratory. William R. Walton prepared many of the samples for study. This work was in part financed by the Office of Naval Research, under contract N6-ONR-277.

METHOD OF STUDY

One-quarter section of the core was furnished for study of the Foraminifera content. This was extracted and prepared by Mr. Johnson and his colleagues and was cut into six-inch lengths, with the top and bottom of each section indicated. The top two inches of each six-inch section furnished was washed and examined for Foraminifera. About one-eighth inch of material was trimmed from the outer surfaces to avoid contamination of the microfaunas which may have been caused by smearing on the inside of the Shelby tubing or in quartering the core.

It was discovered that most of the two-inch sections of samples from beneath the Lower Peat layer (below elevation −24 feet 8 inches) contained few or no specimens of Foraminifera. It seemed important to find whether Foraminifera were present in this lower section of the core, as a basis for knowing whether most of it is of marine or non-marine origin. According-

ly, the complete six-inch section was washed and examined for each of the following samples: 4B, 4C, 4D, 4E, 5C, 6A, 6E, 7A, 7B, 7E, 7F, 7G, 8A, 8B, 8F, 8G, 9A, 9B, 9C, 9E, 9F, 9G, 10C, 11A, 11B, 11C, 12B, 13A, 13B, 13D, 13G, 14D, 15B, 15F, 16D, 17A, 17E, 18C, 18D, 18E, 19C, 19G, 20D, 21,D, 22E, 23B, 23D. Although the results of this examination were mostly negative, a few specimens were discovered and it is believed that the additional effort was justified.

All specimens have been mounted on faunal slides and are in the collections of the Marine Foraminifera Laboratory. In listing the occurrence of specimens, the actual number occurring in each sample is given. Samples taken from the lower peat and above it were approximately two inches in length, and the samples below the peat which contain Foraminifera are all six inches long. Each of these two suites of samples thus contain comparable quantities of sedimentary material, and the relative abundance of the faunas is indicated by the numbers of specimens.

SPECIES OF FORAMINIFERA

The stratigraphic distribution of the Foraminifera is given on Tables XIII and XIV. The following species have been discovered in the samples examined:

Ammoastuta salsa Cushman and Broniman. Plate XIV, 11, 30. Cushman and Broniman, 1948, Contr. Cushman Lab. Foraminiferal Res., vol. 24, p. 17, pl. 3, figs. 15, 16. This species has been described from brackish water of Trinidad, B. W. I. It occurs only in sample 3G in the core. This sample is in the upper part of the lower peat, at a position where Conger found brackish water diatoms.

Eggerella advena (Cushman). Plate XIV, 10. *Verneuilina advena* Cushman, 1922, Res. Hudson Bay Exped., 1920, no. 9, p. 9. This species occurs commonly in the shallow waters off the New England coast and in shallow water from the Arctic and the British Isles. It is suspected that it is characteristic of waters having an approximate salinity range of 30 parts per thousand to 32 parts per thousand, and low winter and high summer temperatures.

Elphidium incertum (Williamson) var. *clavatum* Cushman. Plate XIV, 18. Cushman, J. A. 1930, Bull. 104, U.S. Nat. Mus., pt. 7, p. 20, pl. 7, fig. 10. This variety is a typical shallow water form occurring along the New England coast and also from other Atlantic areas. From its distribution it appears to tolerate a wide variety of water conditions, being perhaps most common in shallow water having low winter temperatures. It probably also represents marine water of rather low salinity.

TABLE XIII. FORAMINIFERA FAUNAS FROM SAMPLES ABOVE THE LOWER PEAT

SAMPLE						1A	1B	1C	1D	1E	1F	2A	2B	2C
Elevation of Foraminifera Sample	+1	+0	−1	−2	−3	−12′5″ to −12′7″	−12′11″ to −13′1″	−13′5″ to −13′7″	−13′11″ to −14′1″	−14′5″ to −14′7″	−14′11″ to −15′1″	−16′2″ to −16′4″	−16′8″ to −16′10″	−17′2″ to −17′4″
PLANKTONIC SPECIES														
Globorotalia truncatulinoides	1													
Pulleniatina obliquiloculata														
BENTHONIC SPECIES														
Ammoastuta salsa														
Cibicides sp.														
Eggerella advena	1													
Elphidium incertum var. *clavatum*						36	54	23				3	3	
Haplophragmoides sp.														
Nonion tisburyensis						66	19	88					6	4
Quinqueloculina cf. *fusca*														
Rotalia beccarii var. *sobrina*						10	1	4						
Trochammina inflata	4	11	78	54	28	6	8			3		1		
Trochammina macrescens				3	1									
Trochammina sp.	1		1	1	3									

SAMPLE	2D	2E	2F	2G	3A	3B	3C	3D	3E	3F	3G	4A	4B
Elevation of Foraminifera Sample	−17′8″ to −17′10″	−18′2″ to −18′4″	−18′8″ to −18′10″	−19′2″ to −19′4″	−19′11″ to −20′1″	−20′5″ to −20′7″	−20′11″ to −21′1″	−21′5″ to −21′7″	−21′11″ to −22′1″	−22′5″ to −22′7″	−22′11″ to −23′1″	−23′8″ to −23′10″	−24′4″ to −24′6″
PLANKTONIC SPECIES													
Globorotalia truncatulinoides													
Pulleniatina obliquiloculata													1
BENTHONIC SPECIES													
Ammoastuta salsa				2		1	1		2		3		
Cibicides sp.			1										
Eggerella advena													
Elphidium incertum var. *clavatum*		3					1						
Haplophragmoides sp.										3	15		
Nonion tisburyensis	1					14	2						
Quinqueloculina cf. *fusca*												4	
Rotalia beccarii var. *sobrina*		2		2		1		1		1			
Trochammina inflata		2	2				1					7	
Trochammina macrescens													
Trochammina sp.										10	11	5	

TABLE XIV. FORAMINIFERA OCCURRING BELOW THE LOWER PEAT

Sample No.	Elevation	Species	No.
7 A	−33′11″ to −34′5″	*Globigerinoides sacculifera* *Sphaeroidinella dehiscens*	1 1
7 F	−36′5″ to −36′11″	*Cibicides* sp. *Globorotalia truncatulinoides*	1 1
8 F	−40′2″ to −40′8″	*Cibicides* sp.	1
9 E	−43′5″ to −43′11″	? *Robulus*	1
13 D	−60′2″ to −60′8″	*Cibicides* sp. *Globigerinoides rubra* *Pulleniatina obliquiloculata*	1 1 1
18 E	−79′8″ to −80′4″	*Nonion tisburyensis* Butcher	3
19 G	−84′7″ to −85′1″	*Nonion* sp.	1
23 B	−97′11″ to −98′5″	*Nonion tisburyensis* Butcher	1

Nonion tisburyensis Butcher. Plate XIV, 17, 25, 36. Butcher, W. S., 1948, Contr. Cushman Lab. Foram. Res., vol. 24, pt. 1, p. 22, text figs. 1, 2. Butcher has described this species from Tisbury Great Pond, Martha's Vineyard, Massachusetts. It is also found in Great Pond at Falmouth, Massachusetts, and presumably it occurs in other similar places along the coast of Massachusetts. Tisbury Great Pond contains brackish water having a salinity which varies from 20 parts per thousand to 30 parts per thousand, and is occasionally frozen in the surface during the winter. *Nonion tisburyensis* is closely related to *N. pauciloculum* and there may be intergrades between the two species. It is possible that *N. tisburyensis* is a brackish water subspecies of *N. pauciloculum.*

Rotalia beccarii (Linnaeus) var. *sobrina* Shupack. Plate XIV, 15, 16. Shupack, B., 1934, Amer. Mus. Novitates, No. 737, p. 6, figs. 4a-c. The material from which Shupack described this variety is from Long Island Sound and New York Harbor. This is a shallow water area having a surface salinity which generally is between 25 parts per thousand and 30 parts per thousand. It is quite probable that this variety also occurs in Boston Bay and adjacent regions but has not been recognized.

Plate XIV

(See opposite page for explanation.)

Plate XIV

Foraminifera From Boston Basin Deposits.

1. *Globorotalia truncatulinoides* (d'Orbigny) (x48) Hancock Life Insurance Building site, elevation -1 ft.
2. *Pulleniatina obliquiloculata* (Parker and Jones) (x70) Hancock core, sample 4-B.

3, 4. *Trochammina inflata* (Montagu) (x48) Hancock Life Insurance Building site, elevation -2 ft.

5, 6. *Trochammina macrescens* H. B. Brady (x48) Hancock Life Insurance Building site, elevation -2 ft.

7. *Trochammina* sp. (x48) Hancock core, sample 4-A.

8, 9. *Trochammina* sp. (x48) Charles River silt.

10. *Eggerella advena* (Cushman) (x70) Hancock Life Insurance Building site, elevation -2 ft.
11. *Ammoastuta salsa* Cushman and Bronnimann (x48) Hancock core, sample 3-G.
12. *Haplophragmoides* sp. (x48) Hancock core, sample 3-F.

13, 14. *Quinqueloculina* cf. *fusca* (C. H. Brady) (x70) Hancock core, sample 4-A.

15, 16. *Rotalia beccarii* (Linnaeus) var. *sobrina* Shupack (Fig. 15, x70; Fig. 16, x48) Hancock core, sample 1-C.

17. *Nonion tisburyensis* Butcher (x48) Hancock core, sample 1-C.
18. *Elphidium incertum* (Williamson) var. *clavatum* Cushman (x48) Hancock core, sample 1-C.
19. *Cibicides* sp. (x70) Hancock core, sample 2-F.
20. *Sphaeroidinella dehiscens* (Parker and Jones) (x48) Hancock core, sample 7-F.
21. *Globorotalia truncatulinoides* (d'Orbigny) (x48) Hancock core, sample 7-F.
22. *Puelleniatina obliquiloculata* (Parker and Jones) (x48) Hancock core, sample 13-D.
23. *Globigerinoides rubra* (d'Orbigny) (x48) Hancock core, sample 13-D.
24. *Globigerinoides sacculifera* (H. B. Brady) (x48) Hancock core, sample 7-A.
25. *Nonion tisburyensis* Butcher (?) (x70) Hancock core, sample 18-E.
26. *Nonion* sp. (x70) Hancock core, sample 19-G.
27. *Robulus* (?) (x70) Hancock core, sample 9-E.

28, 29. *Trochammina inflata* (Montagu) (Fig. 28, x70; Fig. 29, x48) Charles River silt.

30. *Ammoastuta salsa* Cushman and Bronnimann (x48) Charles River silt.
31. *Quinqueloculina* cf. *fusca* (H. B. Brady) (x70) Charles River silt.
32. *Globigerinoides rubra* (d'Orbigny) (x70) Charlestown Navy Yard, elevation -56.5 ft.
33. Young Globigerinid (x70) Cambridge clay pit, elevation -50 ft.
34. Young Globigerinid (x70) Charlestown Navy Yard, elevation -41 ft.
35. *Globorotalia* sp. (x70) Charlestown Navy Yard, elevation -56.5 ft.
36. *Nonion tisburyensis* Butcher (x48) Charlestown Navy Yard, elevation -56.5 ft.

Trochammina inflata (Montagu). Plate XIV, 3, 4, 28, 29. *Nautilus inflatus* Montagu, Test. Biut., Suppl., 1808, p. 81, pl. 18, fig. 3. It is possible that this species lives in the adjacent shallow water marine area at the present time although it has not been reported adjacent to Boston. It occurs in abundance in a marine marsh and adjacent nearshore areas off Barnstable, Massachusetts.

Trochammina macrescens H. B. Brady. Plate XIV, 5, 6. H. B. Brady in G. S. Brady, Robertson, and H. B. Brady, 1870, Ann. Mag. Nat. Hist., ser. 4, vol. 6, p. 290, pl. 11, fig. 5. This has been reported only from the region of the British Isles, but the species in the present sample may live in the Boston region at the present time. Heron-Allen and Earland suggest that it is a low-salinity form.

The genus *Trochammina* is generally characteristic of marine waters of low salinity to brackish water, and it usually occurs in these environments in some abundance. Various species of the genus also occur in oceanic areas, suggesting that *Trochammina* has a wide range of tolerance for both salinity and temperature variation.

The following planktonic species were found represented, usually by single specimens in one or more samples:

Globorotalia truncatulinoides (d'Orbigny)
Globigerinoides rubra (d'Orbigny)
G. sacculifera (H. B. Brady)
Pulleniatina obliquiloculata (Parker and Jones)
Sphaeroidinella dehiscens (Parker and Jones)

These species are all characteristic of the tropical and sub-tropical waters of the Gulf Stream System. These waters have a surface temperature range of approximately 65° to 80° F. in this latitude and a high salinity (approximately 36.5 parts per thousand). Masses of water escape from the Gulf Stream System and carry this planktonic fauna over the continental slope and shelf where it is deposited in the sediments.

THE FORAMINIFERA FAUNAS

Foraminifera occur in some abundance from sample 4A, at elevation −23 feet 10 inches to the top of the core, at elevation −12 feet 5 inches, and also in the samples which were taken from elevation −3 feet to +1 foot. No Foraminifera were found in the samples furnished from the clay pits at Cambridge, Lynn, and Saugus. Below elevation −24 feet 6 inches Foraminifera are very rare in occurrence, a total of only 14 specimens having

been discovered occurring in only 8 of the 116 samples from this section of the core.

The Upper Silt

From just above the top of the Lower Peat to elevation +1 foot, the faunas are essentially similar. They are dominated by *Elphidium incertum* var. *clavatum*, *Nonion tisburyensis*, *Rotalia beccarii* var. *sobrina*, and at least two different species of *Trochammina*. This fauna is essentially the same as the present-day fauna which lives in shallow marine coastal waters of low salinity from the region from Portsmouth, New Hampshire, to Long Island Sound. It is suggestive of rather brackish water which is found near the mouths of estuaries in the region, having a salinity ranging from approximately 25 parts per thousand to 30 parts per thousand. The faunas show some variation in this section. Samples 3E to 3C, from elevation −22 feet 1 inch to −20 feet 11 inches, contain essentially no Foraminifera. There are also practically no specimens in samples 1F to 1D, from elevation −15 feet 1 inch to −13 feet 11 inches. These two zones may represent times either of very rapid sedimentation when the Foraminifera were diluted by the rapid accumulation of detritus or times when the salinity of the water was especially low and these microfaunas did not thrive in abundance.

There is also a rather striking faunal change between the top core sample (1A) at elevation −12 feet 5 inches, and the samples taken from elevation −3 feet to +1 foot. *Elphidium incertum* var. *clavatum*, *Nonion tisburyensis*, and *Rotalia beccarii* var. *sobrina* are abundant in core samples 1A to 1C but do not occur in the samples taken above elevation −3 feet. These upper samples are characterized by abundant specimens of three species of *Trochammina*. The interpretation of this faunal change is in doubt although it certainly indicates a change in the environment in which the calcareous Foraminifera no longer existed and were replaced by a fauna composed entirely of arenaceous species. It is suggested that this change may be correlated with the change in the type of sediment being furnished, as shown by the change in median diameter of the sediments above elevation −11 feet recorded by Judson. Recent unpublished studies of Foraminifera faunas from the shallow waters of the Gulf of Maine, off Portsmouth, New Hampshire, have shown a very striking adjustment of the calcareous and arenaceous faunas to the material of the marine bottom sediment in and on which they live. In general, the arenaceous faunas appear to be adapted to silt areas in which the sediment has a very small median diameter.

The occurrence of two specimens of planktonic Foraminifera in this upper section of the sediment should be indicated. One specimen of *Globorotalia*

truncatulinoides occurs at elevation +1 foot, the uppermost sample studied from the section, and a specimen of *Pulleniatina obliquiloculata* occurs in sample 4B in the middle part of the Lower Peat. As indicated above, these species are characteristic of Gulf Stream water and do not live in the shallow coastal waters of the area at the present time. Their occurrence within this fauna is thus eccentric, and it is believed that they were introduced in stranded masses of Gulf Stream water as discussed below. The occurrence of *P. obliquiloculata* in sample 4B, within the Lower Peat at elevation −24 feet 4 inches to −24 feet 6 inches, clearly shows that this part of the peat is marine.

The Lower Clay Layers

The faunas which occur in the clay below the Lower Peat may be considered as a unit. One striking feature of this material is the sparsity of Foraminifera; specimens were discovered only in samples 7A, 7F, 8F, 9E, 13D, 18E, 19G, and 23B. Three specimens were found in two samples, two specimens in two samples, and only one specimen occurred in the remaining four samples. Another striking feature of these sparse faunas is the occurrence of the Gulf Stream planktonic species in samples 7A, 7F, and 13D.

The presence of Foraminifera in the Lower Clay layers indicates that it was deposited in marine or brackish water, at least during the time of deposition of the samples containing specimens of Foraminifera. It is suggested that all the clay probably was deposited under essentially similar conditions and, if a sufficiently large area could have been sampled, that occasional Foraminifera may have been found at most of the levels. The sparseness of the fauna clearly indicates that the sediment and the enclosed Foraminifera were deposited under conditions quite different from those now obtaining in this area. This also is indicated by the absence of diatoms, as shown by Conger in the accompanying paper. The presence of *Nonion tisburyensis* suggests brackish water conditions, at least in two samples.

It is suggested that these Lower Clay layers were accumulated under conditions of very rapid sedimentation in an estuary. It appears probable that this was during late Glacial or early post-Glacial time in this area, when there was abundant melt water coming from disintegrating glacial ice in the coastal New England region. Under these conditions, the supply of fresh melt water would be expected to be quite variable, due to variations in weather. The estuarine areas in Boston region would thus be subjected to wide ranges in salinity, ranging from water of almost no salt content to an upper limit of perhaps 20 parts per thousand or 25 parts per thousand with a preponderance of lower salinity.

These two factors, rapid and variable rate of deposition and highly variable

salinity, would discourage large populations of Foraminifera. Rapid and large variations in salinity alone might account for the almost complete absence of diatoms, of either fresh water, brackish water, or marine types. It is believed that there are no plant or animal populations which can withstand large and sudden salinity variations. In addition, rapid accumulation of fine-grained sediment is not conducive to the survival of benthonic Foraminifera. This may be due to the paucity of available oxygen a short distance beneath the surface and also due to the poisonous substances produced by the anaerobic bacteria. Recent unpublished work by the writer has shown that living benthonic Foraminifera appear to be confined to the upper centimeter (or less) of the sediment.

The planktonic Foraminifera found in the clay certainly were not indigenous to the area and must have been introduced from Gulf Stream water. The method by which this occurs has been adequately established by Church[1] and by recent work at the Woods Hole Oceanographic Institution. Masses of water commonly become detached from the Gulf Stream and invade the continental shelf area. These water masses retain their identity for a period of time which largely depends upon the weather conditions. It is known that these detached masses carry zooplankton and phytoplankton which are representative of the Gulf Stream and foreign to the continental shelf, and Gulf Stream planktonic species occasionally are found in Massachusetts Bay. The tropical planktonic Foraminifera eventually are incorporated into the sediments in the foreign environment.

Stetson and Parker,[2] in their study of the sediments and Foraminifera of the sediments obtained from the Boylston Street excavation, found more species of benthonic Foraminifera in their clay samples than occurred in the samples examined by the writer. The sites from which the two suites of samples were obtained are approximately 800 feet apart, and the clays are presumed to be correlative. The difference in faunas may be due to an accident of sampling, in which case the fauna here listed is not characteristic of the clay in the John Hancock excavation. On the other hand, if this were an estuary, as here postulated, tremendous local variations in microfauna may be expected even over short distances, due to great variations in salinity and rate of sedimentation or a combination of the two.

Four samples containing Foraminifera were examined recently which were taken from similar deposits occurring in the Boston area. These samples were furnished by Henry C. Stetson and D. F. Eschman of Harvard University. One sample is silt from the bank of the Charles River at the site of the excavation for a new bridge and came from approximately elevation 0 feet. This is material which is not being deposited at the present

[1] Church, 1936. [2] Stetson and Parker, 1942.

time but was laid down in the Charles River estuary at some time during the recent past. Two samples came from a clay obtained in cores taken from the Charlestown Navy Yard, at elevations −41 feet and −56.5 feet. One sample was obtained from the Cambridge clay pit at an elevation of approximately −50 feet.

The sample of Charles River silt contains a Foraminifera fauna dominated by *Trochammina inflata* and also containing *Ammoastuta salsa*, *Quinqueloculina* cf. *fusca*, and *Trochammina* sp. The Charlestown Navy Yard sample from elevation −56.5 feet contains 1 specimen of each of the following: *Globigerinoides rubra*, *Globorotalia* sp., and *Nonion tisburyensis*. Each of the other two samples contain 1 specimen of a juvenile Globigerinid which cannot be identified with certainty. These specimens are illustrated on Plate XIV.

It appears probable that the fauna of the Charles River silt sample is to be correlated with the Upper Silt in the core described in this report. Foraminifera from the Cambridge clay pit sample and the Charlestown Navy Yard samples represent an environment similar to the Lower Clay of the core and probably are approximate correlatives of that deposit.

SUMMARY OF CONCLUSIONS

1. The Foraminifera occurring in the silt layers which occur above the Lower Peat in the John Hancock excavation were deposited under conditions similar to those which now obtain in the shallow waters of Massachusetts Bay. Vertical variations in abundance or nature of the fauna suggest minor changes in rate of sedimentation and other ecologic conditions.

2. Fourteen specimens of Foraminifera have been found in eight samples from the clay layers below the lower peat, and these samples are distributed through almost the total thickness of the clay. It is suggested that the lower clay was deposited in an estuary, that the rate of sedimentation was rapid, and that the changes of salinity of the water were numerous and large.

3. No Foraminifera were found in the samples of clay from Lynn and Saugus, Massachusetts. This does not necessarily prove that they are nonmarine.

4. It is suggested that silt from the Charles River, at elevation 0 feet, is to be correlated with the Upper Silt at the John Hancock site. It is suggested that clay beneath the Charlestown Navy Yard and the Cambridge clay pit be correlated with a part of the Lower Clay at the John Hancock site.

Contribution No. 484 from the Woods Hole Oceanographic Institution.

Contribution No. 1 from the Marine Foraminifera Laboratory.

Woods Hole, Massachusetts.

THE DIATOMS

PAUL S. CONGER

INTRODUCTION

IN the interim between publication of the exhaustive study of "The Boylston Street Fishweir,"[1] and the opening up of deposits a city square away, at Berkeley and Stuart Streets, by the John Hancock Insurance Company building excavation, the unfortunate death of Dr. David Linder has necessitated the finding of someone else to take over the study of the diatoms, a prominent element in the deposits of this later site.

It is the more regrettable that Dr. Linder could not have continued in this present study, both because his thorough acquaintance with the local area, and his famliarity with the materials of the previous site, should logically have resulted in a better correlated analogy, than is possible through studies by two separate individuals, where minute comparison of the two deposits so geographically, topographically, and presumably ecologically close to each other, can be expected as the chief interest derivable from the study.

In assuming this responsibility, I wish first to compliment Dr. Linder's previous careful and able study, and to acknowledge its considerable benefit in facilitating examination of the present materials, as reported here. I attempt to follow in general the same plan, terminology, and approach, as used by Dr. Linder, in order to enhance comparison. However, the reader needs to bear in mind that stated likenesses or differences of corresponding levels of the two deposits cannot be taken as too literally comparable, for the reasons, above mentioned, of possible differences of interpretation by two persons.

Access was had to the references mentioned by Dr. Linder, and to other general works of diatom literature in making the present study.

LOWER CLAY DEPOSITS

A potentially interesting difference in the materials available from the John Hancock excavation and those from the earlier Boylston Street excavation, was the securing in the newer site of a practically continuous core of the sediments to a depth of 109 feet (bed rock), whereas the Boylston Street

[1] Johnson, et al, 1942.

sampling extended to only 23 feet below Boston Base. There is, therefore, in the Boylston Street study no comparable analogue for the portion between −23 feet and −109 feet, Boston Base.

It was strongly hoped that in the core section covering this lower group of sediments, besides the geological constituents of sand and clay expected (thoroughly analyzed and discussed by Judson in his accompanying report), that there might also be found throughout, or at various levels, the characteristically persistent shells of diatoms, to throw additional light on the geological history of the sediments, and conditions prevailing at various times of deposition.

The core sediments below the −25 foot level (Sample No. 4-B), however, proved very disappointing in this respect, being instead the rather consistent "blue clay", interspersed at occasional intervals with pockets of layers of sand, and sizeable pebbles (as in Judson's analysis), but completely devoid of diatoms, or their recognizable remains, and likewise of sponge spicules, often found in the same environment.

The complete absence of recognizable diatom or spicular remains naturally precludes their desired usefulness as indicators, but the whole situation suggests some discussion of pertinence nevertheless, concerning which several comments are worthy of mention.

These lower sediments, particularly those of the clayey-fine-sand type, are such as might well have been deposited in an environment favorable to diatom growth. Whether diatoms could have once lived here and subsequently disappeared, or whether the sediments were always devoid of them is a question.

Such subsequent removal could be effected through either (1) sorting action of the water, or (2) corrosion and chemical dissolution. But particle size is such that sorting could not account for such complete separation, and, besides, the presence of occasional larger pebbles suggests conditions of deposition in which sorting would not have been a major factor, such, for instance, as mass deposition by outwash.

As to the second means of removal, it is a moot question whether submerged clay sediments provide an environment, both unfavorable to diatom growth, and favorable to chemical action tending to solution of diatom shells. As evidence, certain lake deposits of clay are sparse or lacking in diatom remains a short depth below upper, or surface, levels containing them in abundance. In the John Hancock excavation clays, throughout, were found occasional clear fragments simulating short lengths of sponge spicules, but apparently they were not, at least none being identifiable as such. If spicules had been present it is almost certain some recognizable frag-

ments would remain, and that then diatoms might likewise be expected. But breaking and corrosion of spicules to point of obliteration could be expected to quite completely remove all trace of the diatoms, which are of lighter structure. Such assumptions are hardly tenable as applying to the sediments in question.

The likelihood, therefore, of diatoms (or sponges) having been present at all in the waters that deposited these clays (John Hancock excavation, –25 to –109 feet) seems rather questionable, or, further, quite improbable; and another idea explanatory of their absence in an otherwise presumably suitable environment suggests itself. It is this: that the clays, of glacial origin (as stated by the geologists), were laid down at such a rate and under such disturbing physical conditions as to preclude a quiescent stability needed for continuing diatom growth. To support this idea it would seem that the depth of the clays, some eighty feet, represents a fairly rapid deposition in the period covered, affording thereby little foothold for bottom-living organisms, and creating a suspension or turbulence, depriving plankton or pelagic forms of the light necessary to their growth.

This latter explanation of the absence of diatoms seems the one most likely to the writer, and if correct, their absence, in lieu of the more interesting advent of finding them, has some slight significance in accounting for the mode of deposition.

In the coarser sand layer between about –25 and –27 feet (Samples No. 4-B to 4-G), the grinding action of shifting sand, together with sorting action of water movement, might reasonably account for destruction of diatom shells and removal of their remains.

SIMILAR CLAYS FROM NEW ENGLAND TELEPHONE AND TELEGRAPH COMPANY EXCAVATION, AND MISCELLANEOUS SITES

Other blue and yellow clays, including seven samples from 8 feet above, to 16 feet below, Boston City Base, in the New England Telephone and Telegraph Company excavation, contained no diatoms. Miscellaneous samples from Blakely Clay Pit, West Lynn, North Cambridge, Fresh Pond Clay Pit, and Saugus, likewise yielded no diatoms.

THE UPPER CORE

Above the level of –25 feet, Boston Base (Sample No. 4-B) diatoms occurred continuously in more or less abundance in all sediments up to and somewhat above the datum level, and were present generally in a good state of preservation and great profusion of species.

They were conspicuously abundant in the peat layer at –24 to –25 feet, making up an estimated possible 50 per cent or more of the total bulk of the sample, and again in considerable abundance in the highly organic sediments a few feet above and below Boston Base, contributing, thus, to the formation of a quite well-defined Lower Peat layer, and a typical, but somewhat less clearly marked Upper Peat.

It is noteworthy that the levels of the sediments in the John Hancock excavation do not correspond exactly with those in the Boylston Street site, by several feet. At Boylston Street, the upper limits of the clay deposits reached to –16 feet 2.4 inches, and in the John Hancock excavation to about –25 feet. There was, just above these levels, in the Boylston Street site, a peat layer about 6 inches thick, and in the John Hancock excavation a peat layer 1 foot to 13 inches thick. The line of separation between the clay-sand elements of the lower core and this peat layer is quite sharp, but above, it grades more gradually into the sand-silt section of the upper core.

THE LOWER PEAT

In the John Hancock excavation, the material of the peat layer between –24 and –25 feet, which it was possible to obtain directly by hand, as well as from the coring tube, proved to be among the most interesting and productive of the sediments from the standpoint of its diatom content. Because of the care with which it could be taken by direct hand sampling, it was possible to obtain a sample at each inch level through the thirteen-inch layer. These were studied in great detail, and lists of species of the upper and lower parts of the layer with their relative abundance are found in the Tables XV and XVI. Also, a numerical list of the samples taken at each inch interval (numbering from 0 at the bottom, to 12 at the top) gives a general descriptive account of the rather marked and interesting transition from fresh-water to marine dominance which occurs between the lower and upper parts of the layer. This striking transition is the most positive and significant result of the diatom examination of the sediments, and is so profusely evidenced by typically representative species in the two groups as to be easily recognizable even by someone not too familiar with diatoms.

Although the Boylston Street and John Hancock excavation peat layers are not by any means identical, and there is no strict reason from the diatom analysis for assuming that they are the same formation, there are points of similarity which do somewhat indifferently, or perhaps strongly, suggest that. The inference is that they are chronologically the same, ecologically different, groupings, due to varied environmental conditions over a small

localized area, just as one might find today in varied indentations of the same coastal region.

To return to the similarities of the two peat layers: Dr. Linder found few diatoms, but including *Navicula* (*Pinnularia*) *major*, a typical fresh-water species, in the lower part of his peat material, then a sand layer, and above that an upper part richly populated with diatoms about equally representative of fresh-water, brackish, and marine forms. In the peat layer samples ex-

TABLE XV. DIATOMS FROM THE LOWER PART OF THE LOWER PEAT LAYER. (Fresh water flora.) SAMPLES NO. 2 AND 3.

Species	Frequency
Cyclotella Meneghiniana Ktz.	+
Cymbella Cesatii (Rabh.) Grun.	+
Cymbella cymbiformis (Ktz.) Bréb.	+
Cymbella lanceolata (Ehr.) Kirchn.	++
Diploneis elliptica (Ktz.) Cl.	+
Diploneis puella (Schum.) Cl.	+
Eunotia lunaris (Ehr.) Grun.	++
Eunotia major (W.Sm.) Rabh.	++
Eunotia monodon Ehr. (and vars.)	++
Eunotia praerupta Ehr.	++
Eunotia praerupta Ehr. var. *bidens* Grun.	++
Gomphonema intricatum Ktz.	+
Gomphonema parvulum Ktz.	+
Hantzschia amphioxys (Ehr.) Grun.	+
Melosira crenulata Ktz.	+
Melosira italica (Ehr.) Ktz.	+
Neidium bisulcatum (Lagerst.) Cl.	+
Pinnularia acrosphaeria (Bréb.) Cl.	+
Pinnularia appendiculata (Ag.) Cl.	++
Pinnularia borealis Ehr. (var.)	+
Pinnularia divergens W. Sm. (and var. minor)	+
Pinnularia gentilis (Donk.) Cl.	+++
Pinnularia lata (Bréb.) W. Sm.	++
Pinnularia major Ktz.	+++
Pinnularia nodosa f. *capitata* Cl.	+
Pinnularia rupestris Hantzsch	++
Pinnularia viridis (Nitzsch) Ehr.	++
Navicula ambigua Ehr. (with craticular plates)	+
Rhopalodia gibberula (Ehr.) O'Mull. (and vars.)	+
Stauroneis Americana Heid.	+
Stauroneis anceps Ehr.	+
Stauroneis phoenicenteron Ehr. (vars.)	+

amined by me from the John Hancock excavation, the lower samples, Nos. 1, 2, and 3, include a rich and exclusively fresh-water population, above which, although there is not a sharp sand layer, the diatom population in samples Nos. 5, 6, 7, and 8, dwindles down to very sparse or almost none, with sand and coarse organic plant fragments dominating, then in samples No. 10 and 11, a rich, dominantly marine, but fairly well mixed fresh-water, brackish, and marine diatom flora arises; so that we have apparently a parallel transition in the two deposits, but not as pronounced or richly represented in that examined by Dr. Linder, except possibly in the upper portion of his Lower Peat, where he reports the diatoms as plentiful. These circumstances might be explainable on the basis that the Boylston Street Lower Peat is a layer only half as thick and perhaps formed under less luxurious conditions of organic growth. In line with this thought is the very meager occurrence reported by Dr. Linder in the lower portion of his Lower Peat, of anything simulating the diverse fresh-water population so richly present in the John Hancock deposit, lower part, which may be assumed to indicate that the bed Dr. Linder was dealing with was formed at a higher (perhaps sloping shore) level, representing an area, marginal, or very shallow (nearly dry) at that time and unfavorable to accumulation of diatoms.

A further hint of shallowness and part-time drying in the two deposits, in their very lower layer, is the finding of a numerically few and limited kinds of such diatoms as (in the John Hancock deposit) *Navicula borealis*, *Hantzschia amphioxys*, *Navicula ambigua*, and others, that inhabit such an environment. The shells in the lower parts of the two deposits were badly corroded, a condition which often occurs as expressed in Barghoorn's collection notes, "This level appears to have been exposed to aerobic action a large part of the year—perhaps normal soil processes account for the physical condition of the plant constituents and diatoms."

On the other hand, this layer at the John Hancock excavation, would seem to have been laid down in a somewhat deeper depression than in the Boylston Street site, such as a shallow lake or shore lagoon, close to but protected from the sea, where freshwater diatom growth and accumulation was well favored—the difference in level of 7 feet could very nicely account for such contrasting conditions—although these ideas are, of course, largely hypothetical.

Whatever circumstances prevailed, it is certain knowledge that the John Hancock site was protected from the sea at this time so effectively as to permit growth of a distinctly and exclusively fresh-water flora. It is interesting to follow the somewhat later influx of such forms as *Nitzschia scalaris* in considerable numbers, *Navicula maculata*, forms which seem to like shallow

Table XVI. Diatoms from the Upper Part of the Lower Peat Layer. (Mixed flora, dominantly marine.) Samples No. 10 and 11.

Species	Marine	Brackish	Fresh
Achnanthes brevipes Ag.	++		
Achnanthes intermedia Ktz.		++	
Actinocyclus Ralfsii W. Sm. (and var. sparsus Greg.)	++++		
Amphiprora conspicua Grev.		+	
Amphora proteus Greg.	+		
Brébissonia Boeckii (Ehr.) Grun.		+	+
Biddulphia laevis Ehr.	++	++	++
Caloneis silicula (Ehr.) Cl.			++
Caloneis trinodis (Lewis) Boyer		++	++
Campylodiscus echeneis Ehr.	++++	++++	
Cocconeis Placentula Ehr.		++	++
Coscinodiscus Kützingii A. S.	+		
Coscinodiscus radiatus Ehr.	+		
Cyclotella operculata (Ag.) Bréb.		+	+
Cyclotella striata (Ktz.) Grun.	+	+	
Cymbella americana A. S.			+
Diploneis elliptica (Ktz.) Cl.		+++	+++
Diploneis Gründlerii (A. S.) Cl.	+		
Diploneis Smithii Bréb.	+++		
Epithemia turgida Ktz.			+
Eunotia major (W. Sm.) Rabh.			++
Eunotia pectinalis (Ktz.) Rabh. (and vars.)			++
Eunotia praerupta Ehr. (and vars.)			+++
Frustulia vulgaris (Thw.) DeToni			+
Gomphonema augur Ehr.			+
Grammatophora marina (Lyngb.) Ktz.	+		
Mastogloia Smithii Thw.	++		
Melosira granulata (Ehr.) Ralfs			+
Melosira Jurgensii Ag.	++	++	
Melosira sulcata Ktz.	+	+	
Melosira undulata (Ehr. Ktz.)		++	++
Naiucula cuspidata Ktz.			+
Navicula elegans W. Sm. var. *cuspidata* Cl.	+++	+++	
Navicula granulata Bréb.	+		
Navicula maculata (Bail.) Cl.	+	+	
Navicula peregrina (Ehr.) Ktz.		++++	
Navicula Semen Ehr.			++
Neidium affine var. *amphirhynchus* (Ehr.) Cl.			+
Nitzschia circumsuta (Bail.) Grun.		+	
Nitzschia compressa (Bail.) Boyer	++	++	
Nitzschia granulata Grun.	+	+	
Nitzschia obtusa W. Sm. var.		++	
Nitzschia panduriformis Greg.	+++	+++	
Nitzschia plana W. Sm.		+	
Nitzschia scalaris (Ktz.) W. Sm.		++++	
Nitzschia tryblionella Hantzsch		+++	
Pleurosigma obscurum W. Sm.	+	+	
Pinnularia dactylus Ehr.			++
Pinnularia lata (Bréb.) W. Sm.			++
Pinnularia major Ktz.			+++
Pinnularia viridis (Nitzsch) Ehr.			++
Rhabdonema adriaticum Ktz.	+		
Rhopalodia gibba (Ehr.) O'Müll.		+	+
Rhopalodia gibberula (Ehr.) Ktz.	++	++	++
Rhopalodia musculus Ktz.		+++	
Stauroneis acuta W. Sm.			+
Stauroneis americana Heid.			++
Stauroneis anceps Ehr.			+
Surirella amphioxys W. Sm.			+
Surirella crumena Bréb.		++	++
Surirella ovalis Bréb.	+	+	+
Surirella recedens A. S.	+	+	
Surirella tenera Greg.			++
Synedra pulchella (Ralfs) Ktz.			+
Tabellaria fenestrata (Lyngb.) Ktz.			+

lakes very close to the sea, and later of brackish forms like *Navicula semen* and *Navicula peregrina*, running into the development of the rich flora of mixed character heretofore mentioned.

This seems to me to point rather significantly to the idea that the land (coast of the continent) must have sunk sufficiently to depress a shallow water area or shore lake, to a level permitting the sea to overrun it and gradually supplant the original fresh-water diatom flora with a dominantly and typically marine one, though mixed for a long period with fresh-water forms carried in or stirred up from the previous sediments.

In these marine sediments the presence of *Campylodiscus echeneis* and *Actinocyclus Ralfsii*[2] (and var. *sparsus*) is outstanding, and though the flora is diverse and rich in many species, they are conspicuous, along with the afore mentioned *Navicula maculata*. The relative sparsity of such typical epiphytes as *Achnanthes* and *Grammatophora*, and others, suggests that, although the water was shallow it was perhaps not filled with higher aquatic growth at that time, though some such growth probably occurred.

The consecutive decline of this *Actinocyclus* in the higher elevations of the Hancock sediments may be looked upon also, possibly, as supporting the idea of a deepening of the water, increase of turbulence, and climatic lowering of temperature.

SEDIMENTS ABOVE THE PEAT LAYER

In the sediments two or three feet immediately above the Lower Peat layer, the relative species content of the diatom flora, remains very much the same, but gradually lessens in quality, until in Sample No. 3-B, and above, the diatoms become relatively scarce compared to the sand content. There is a marked tendency, too, for *Actinocyclus Ralfsii* var. *sparsus* to disappear, and for *Campylodiscus echeneis* to become correspondingly more conspicuous, by contrast.

[2] I think it probable that the name given to the diatom figured in Dr. Linder's plate, and subsequently also listed in his Table III, is a typographical error, and should be *Actinocyclus Ralfsii* instead of *Rothii*, of which I find no record; he mentions *A. Ralfsii* later in his Table V. The matter puzzled me for some time, and I mention it here both to correct an error, and because the diatom (*A. Ralfsii* and its var. *sparsus*) or *A. sparsus* as some choose to call it, is so prominent a form in my material that it is desirable to determine its identity and correspondence in the two deposits. Apparently it is not quite as abundant in Dr. Linder's material as it seems to be in the John Hancock peat, although he mentions it as moderately frequent in his Table III (*A. Rothii*), and becoming less so in his Table V (*A. Ralfsii*), if they are the same, and he comments on it as "a marine species found in the lower strata." This agrees well with its history in the John Hancock sediments also.

Navicula peregrina comes into the flora somewhat more numerously, and other changes also take place. Such also conspicuous forms as *Nitzschia panduriformis*, *tryblionella*, and *granulata*, maintain their occurrence very consistently throughout the upper layers. *Rhopalodia gibberula*, a warmer water form, dies out markedly, and there are more and more frequently *Pleurosigma balticum* and *Tropidoneis vitrea*. A gradual but noticeable transition—and possibly toward a cooler water flora as suggested by *P. balticum*, mentioned by Linder—occurs, as one moves upward in the sediment. A rather plentiful and diverse diatom flora at the levels −3 to +1 inclusive is discussed later under the heading of Upper Peat, which, though not a true peat but more a silty-sandy-mud, is so represented because of its peat-like texture and color, and probably corresponds to the Upper Peat layer of Dr. Linder's report.

From the −12 feet 5 inches to −3 inch levels (Sample No. 1-A to Upper Peat) no samples were available in the John Hancock excavation unfortunately, so that the diatom record here is interrupted, for 9 feet, elevation. From the relatively uniform trend and somewhat sparse diatom content of the sediments below this −12 feet 5 inches to −24 feet, I think it likely that a continuing sparse diatom flora obtained through the missing nine feet, consistent with the general correspondence between this and the material studied by Dr. Linder. If so, then nothing of unusual significance was lost in the missing section, as this range of elevation in the sediments represents a rather impoverished and monotonous unchanging sequence.

The relative paucity of diatom remains in the higher elevations of the deposit does not necessarily mean decreased abundance of diatom growth —although it well may— at these levels. A somewhat higher proportion of larger size sand grains might mean a stronger tidal and water disturbance during the period represented by these particular depths of deposit, due perhaps to sufficient, though not great, sinking of the land, to permit stronger invasion from the sea. Under these circumstances, although diatom growth might perhaps be fully as luxurious as in the richer deposits below—the peat layer where the water must have been relatively quiet to permit accumulation of such concentrated diatom sediments—the accumulation of the diatom shells would be much less in proportion, due to the washing out of the lighter diatom structures by water movement, and relative concentration of the heavier sand particles.

If this assumption is correct, it could be further borne out by the relative decrease in numbers of diatom species with lighter shells, in deference to a correspondingly higher proportion of those with heavier shells, accounting for the predominance of such forms, for instance, as *Melosira*

sulcata, Nitzschia panduriformis, and particularly *Campylodiscus echeneis.*

Another, rather suggestive evidence, of slow sinking of the land, in addition to that of the afore-mentioned transition from fresh-water to marine forms in the peat layer, is the gradual, though quite noticeable decrease in diatom numbers in the sediments immediately above the peat for a distance of two or three feet of elevation, while the species content remains fairly uniform.

One fact, of at least casual interest, is obvious throughout the 25 feet of sediment containing diatoms in the John Hancock deposit: that is, that the sediments are almost monotonously uniform and the changes are very gradual indeed, no sharp changes occurring, the sharpest being that of the fresh-water to marine transition within the Lower Peat layer. Even the upper level of the peat layer, though perhaps more distinctly different in color and gross appearance, can hardly be said to be sharp in any sense of the term, because of the slow changes in diatom content and sand particle size.

In some of the higher levels (at intervals between Samples No. 3-B and 1-D, or above) the relative sparsity, or low population, of diatoms may be adversely reflected in more prolific sponge growth as indicated by the finding of larger numbers of sponge spicules. The occurrence of any massive sponge growth would be a considerable deterrent to heavy diatom production because of substitution, rather than any incompatibility. However, there are few levels where the spicule content is high enough to indicate this as an important factor.

Though the sediments are rather uniform in texture, generally speaking, there are places where single large pebbles (half inch or more in diameter) occur, and it is difficult to account for such isolated occurrences, except they were by some manner thrown into the sediment. Well-preserved shell layers at certain levels are perhaps indicative of variations in water acidity, but these seem hardly to have had any effect on the relative diatom succession.

THE UPPER PEAT

Within a depth of 3 feet below to about 2 feet above Boston City Base, the land-sea level relationship had apparently reached another state of quiescent stability favorable to a heavy diatom population and partial peat deposition; at least the material is highly organic, with a considerable diatom content, though by no means as concentrated as in the lower, typical peat.

A wide variety of species (Table XVII) not appreciably different from what is found in the vicinity today, is suggestive that climatic conditions, and ecological conditions, were also similar.

Table XVII. Diatoms from Strata Near Level of Boston City Base.
(From −3 to +2 feet, Boston City Base. Dominantly marine.)

Species	Marine	Brackish	Fresh
Achnanthes brevipes Ag.	++		
Achnanthes intermedia Ktz.		++	
Actinoptychus undulatus (Bail.?) Ralfs	+	+	
Amphiprora alata Ktz.		+	
Amphora Eulensteinii Grun.	++		
Amphora proteus Greg.	++		
Auliscus caelatus Bail.	+		
Biddulphia aurita (Lyngb.) Bréb.	+		
Biddulphia (*Triceratium*) *sculpta* (Shad.) V. H.	+	+	
Brébissonia Boeckii (Ehr.) Grun.		+	+
Caloneis Liber (W. Sm.) Cl.	+		
Campylodiscus Thuretti Bréb.	+		
Cocconeis scutellum Ehr.	++	++	
Coscinodiscus Kützingii A. S.	+		
Coscinodiscus radiatus Ehr.	+		
Diploneis bomboides A. S.	+		
Diploneis bomeus Ehr.	+		
Diploneis crabro Ehr.	+		
Diploneis elliptica (Ktz.) Cl.		+++	+++
Diploneis Gruendlerii (A. S.) Cl.	+		
Diploneis interrupta (Ktz.) Cl.	+		
Diploneis Smithii Bréb.	+++		
Grammatophora marina (Lyngb.) Ktz.	+		
Melosira jurgensii Ag.	++	++	
Melosira sulcata Ktz.	+++	+++	
Navicula brevis Greg.	+		
Navicula digito-radiata (Greg.) Ralfs (and var. *Cyprinus* (Ehr.) V. H.	++++	++++	
Navicula directa (W. Sm.) Ralfs	+		
Navicula formosa Greg.	+++	+++	
Navicula granulata Bréb.	+		
Navicula Lyra Ehr.	+		
Navicula peregrina (Ehr.) Ktz.		++++	
Nitzschia acuminata (W. Sm.) Grun.	++	++	
Nitzschia circumsuta (Bail.) Grun.		+	
Nitzschia compressa (Bail.) Boyer	++	++	
Nitzschia granulata Grun.	+	+	
Nitzschia (*Tryblionella*) *levidensis* (W. Sm.) Grun.	++	++	
Nitzschia longissima (Bréb.) Ralfs	+		
Nitzschia panduriformis Greg. (and vars.)	++	++	
Nitzschia paradoxa (Gmel.) Grun.	+	+	+
Nitzschia plana W. Sm.	+		
Nitzschia punctata (W. Sm.) Grun.	+++	+++	
Nitzschia Sigma (Ktz.) W. Sm. (and var. *sigmatella* (Greg.) Grun.	++++	++++	
Nitzschia Tryblionella Hantzsch		++	
Pleurosigma angulatum (Quek.) W. Sm.	+		
Pleurosigma Balticum (Ehr.) W. Sm.	++++	++++	
Pleurosigma obscurum W. Sm.	++	++	
Rhabdonema Adriaticum Ktz.	+		
Rhabdonema arcuatum (Lyngb.) Ktz.	++	++	
Rhoicosphenia curvata (Ktz.) Grun.		++	++
Rhopalodia gibberula (Ehr.) Ktz.	+	+	+
Scoliopleura latestriata (Bréb.) Grun.	+++	+++	
Scoliopleura tumida (Bréb.) Rabh.	++	++	
Surirella crumena Bréb.		+	+
Surirella fluminensis Grun.		+	+
Surirella gemma Ehr.		+	
Surirella ovalis Bréb.		+	
Surirella recedens A. S.	+	+	
Surirella striatula Turp.		+	
Trachyneis aspera (Ehr.) Cl. (and vars.)	++		
Tropidoneis lepidoptera (Greg.) Cl.	+		
Tropidoneis vitrea (W. Sm.) Cl. ?	++	++	

SUMMARY AND DISCUSSION

Diatom remains are found in the John Hancock excavation sediments only to a depth of −25 feet, with no sign of them, nor of associated remains, in the underlying clays between −25 and bedrock located at −109 feet. Rather rapid outwash deposition of these clays may possibly have caused too much muddiness and "silting out", with consequent opacity, to offer an environment suitable to diatom growth.

A lower peat layer, 13 inches thick, and a more indefinite peaty mud layer at the level of Boston City Base, reveal a concentrated diatom population, but the sediments in between are rather uniformly sparse in diatoms.

The Lower Peat, −24 to −25 feet, is the most concentrated, interesting, diverse, and significant aspect of these sediments, containing two concentrated layers. The lower 2 to 3 inches is a fresh-water layer. Above this, 9 to 12 inches above the lower interface of the peat, is a marine layer having a diatom population estimated to comprise 50 per cent. or more of the deposit. These diatoms are dominantly marine mixed with fresh and brackish water species. In between these two concentrated layers is a transition zone in which diatoms become very scarce or absent. This zone represents a lowering of the land level and invasion by the sea, thus to submerge the fresh-water layer and infiltrate the deposit with a dominantly marine flora, which persists in varied abundance up through the remainder of the sediments to the level of Boston City Base.

The fresh-water influence upon the deposits becomes rapidly less with height in elevation, until in the upper sediments fresh-water diatoms are only occasional and doubtless carried in. The fresh-water layer in the Lower Peat was presumably formed in a shallow, "grassy" lake or shore lagoon, entirely cut off from the sea.

Above the marine layer of the Lower Peat the same marine flora maintains, but diminishes proportionately in numbers, for several feet upward in the sediments, then almost dies out and changes some in species.

In my opinion the changes in diatom flora at different levels in the deposit, which are very gradual and slight, and have to do more with variations in relative abundance of certain of a continuing group of species than with the dropping out or introduction of entirely new forms, provide no very conclusive or definite information of any decided changes in conditions. I believe they are due to comparatively slight ecological variations or fluctuations in the environment, such as one may frequently encounter in any small local area today, the causes of which cannot be specifically accounted for because of either: (1) our lack of knowledge of the very specific require-

ments of individual species of diatoms, or (2) too many or complex a group of factors involved.

In the marine layers (Samples Nos. 4-A, 3-G, 3-F, etc.) *Actinocyclus Ralfsii* and its var. *sparsus*, and *Campylodiscus echeneis* are conspicuously abundant, and a wide variety of other species is plentiful. Much the same type of flora persists through the sediments up to Sample No. 3-B, where, however, the *Actinocyclus* practically disappears, and the whole diatom population becomes much less numerous.

The dropping out of *Actinocyclus*, and the incoming to the flora of *Pleurosigma balticum*, may, as Dr. Linder has suggested, mean a trend to somewhat cooler mean temperature. If this is true, it would seem that the analyses of the pollen remains in the sediments should probably be more definitely indicative of the climatic transitions, the pollen being derived largely from land plants subject to a wider range of variation of environmental factors.

On the whole, the diatom flora, and probably the environmental features conditioning it are not greatly different from that which exists in the vicinity today. Only a much more highly specific knowledge of the most favorable factors of individual species could account for the gradual and subtle changes prevailing, and even that is doubtful where so many species and variable factors are involved.

Practically nothing of significance, except the distinct fresh-water-marine transition in the Lower Peat, has been added through study of the John Hancock excavation deposits, to the findings of Dr. Linder at Boylston Street, save a correlation and corroboration of his work, which is in itself of some interest.

PROFILE. GENERAL DESCRIPTION OF LAYERS OF THE LOWER PEAT

(Taken each inch through 13 inches)

Sample No. 0. Sandy. Diatoms very scarce, fragmentary and eroded: consist mainly of occasional large naviculoid forms, now and then a *Eunotia*.

Sample No. 1. Diatoms numerous, many fragmentary and corroded. Signs of strong aerobic action, but apparently a rich diatom flora flourished.

Sample No. 2. Black organic peat, practically no sand. Diatoms abundant, fresh-water. Lacks evidence of strong corrosion in previous two samples.

Sample No. 3. As in No. 2. Diatoms abundant. This is entirely fresh-water and the richest in diatoms of the Lower Peat sediment.

Sample No. 4. Same as No. 3.

Sample No. 5. Diatoms plentiful, entirely fresh-water, mainly of large Naviculoid types, and much as in previous three samples, but with larger proportion of dense lignified plant tissues.

Sample No. 6. Diatoms numerous and well preserved; much as in No. 5, with much ligneous plant tissue. Naviculoid and *Eunotia* type diatoms predominating.

Sample No. 7. Diatoms plentiful but not numerous; Naviculoid and *Eunotia* types, with *Navicula semen* Ehr. becoming more and more abundant as in previous two samples. Much coarse plant fiber.

Sample No. 8, Diatoms very few, corroded. Largely plant fiber. Area may have reached marshy and acid condition with little open water suitable to diatoms.

Sample No. 9. Diatoms very scarce; fresh-water still. Species as in previous samples. Much coarse plant fiber.

Sample No. 10. Diatoms plentiful, though not abundant, or dominant. Sample has large proportion of organic matter and ligneous plant remains. A marked change in diatom type is seen, to brackish and marine forms in addition to fresh-water. *Nitzschia scalaris*, *Campylodiscus echeneis*, and *Actinocyclus Ralfsii* (with var. *sparsus*) are conspicuous. A wide variety of forms present.

Sample No. 11. Similar to No. 10, but diatoms very numerous, and making up large portion of sample. This sample is richest of the upper part of the Lower Peat. In sample No. 11, fresh-water, brackish, and marine forms are about equally mixed, but, if anything, it has a dominantly marine appearance, and marine forms are too numerous to indicate a mere occasional invasion by the sea, but must rather have been the result of an established salt-water habitat.

Sample No. 12. Similar to Nos. 10 and 11, but with perhaps a somewhat lesser diatom content. Considerable sand and silt. *Actinocyclus* is a most prominent form.

The above description of this profile indicates a clear transition from fresh water to marine habitat. A gradual sinking of the land is suggested, with the middle layer samples (Nos. 7 and 8) representing probably a period of stagnation, with a killing off and lessening of the fresh-water diatom content, and a lapse before the area became thoroughly saline and acquired a well-established and flourishing marine diatom flora, in its place.

The profusion of variety, and abundance of individuals, dominated in the lower part of the layer by large *Naviculoid* (*Pinnularia*) forms with heavy

silica shells, suggests a shallow water body, with either good spring or seepage supply, or slow runoff of cold water, well loaded with nutrients, notably silica.

The presence of several typical brackish forms *Nitzschia scalaris, Navicula maculata, Diplonies elliptica, Navicula peregrina, Rhopalodia gibberula,* and others; suggests a period of transition when the trespassing by the sea may have been infrequent and temporary, before the area was more strongly flooded with salt water.

The increase in numbers of *Navicula Semen* Ehr. strikes one's attention. Cleve says of this species that it "seems to be a northern species, rarely found living, but frequently in postglacial deposits of Scandinavia and North America," and again says it is common in diatomaceous earths of northern latitudes, including the northern United States and Canada.

Although the nomenclature of Cleve (*Caloneis, Diploneis, Pinnularia,* etc.) is used to be consistent with Linder's report, I prefer generally to adhere to that of Schmidt, Van Heurck, and Mann, in including these various groups in the older genus *Navicula.*

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SUMMARY

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It has fallen to my lot to summarize the results which have been achieved by the several investigators. The collaborative venture here presented is actually a continuation of investigations begun in 1939. The present work elaborates and, in places, corrects the results of previous research. While the papers included here stand as contributions in their own right, they are more comprehensible if considered together as a unit which includes the work published in 1942. This latter also presents some details which were not repeated here.

It is obvious that a complete summary of the work accomplished would consist of a number of sections presenting the results in the light of each line of research which has been followed. This not only would be a valid procedure but it is likely that such might increase the significance of the work. However, a summary of this sort requires of a single author special and detailed knowledge of many scientific disciplines. Attempts to educate me along all these lines have had but indifferent success and so the following is but a generalized brief exposing a long-standing interest in the problem and a desire that adequate attention be given to every facet of it.

Because of their relation in respect to sea level and the deposits which surround them, the stakes of the fishweirs are indisputable evidence of the earliest known event in the human history of Boston. However, if the matter were to be argued in court it would be a case of *corpus delecti.* We know nothing concerning the people who cut and drove the stakes. Our ignorance may not be permanent for, as Judson has pointed out, future excavations on the shores of the ancient Back Bay (Fig. 13) may well bring to light the habitation sites and some details of the culture and way of life of these early New England fishermen. In the meantime, some inferences of anthropological nature are of significance.

If we may assume that several fishweirs existed, it follows that an aboriginal community of some size and permanence was established along the shores of the ancient Back Bay. It is impossible to conceive that this community existed in a vacuum. New England, and by implication the northeastern part of North America, was the home of an established population at this time. It is disquieting to realize that some of the patently early but as yet undatable

communities which have been found by archaeologists may well have been inhabited by cousins, uncles, or grandfathers of the fishweir builders.

The data from this and previous studies is the basis for an additional assumption which inevitably must color our thinking concerning human history in the northeast. Since the fishweirs were built, and as a matter of fact for a considerable period previous to this time, there has been no change in the environment which would seriously modify human life. We may even point out that during and back of "Fishweir Time" conditions were more favorable for agriculture than they are now. However, we are not yet prepared to defend a statement that our early fishermen may have raised crops! We have to recognize the probability of a continuous occupation of the Northeast for an absolute minimum of three or four thousand years. The extent and character of this occupation would be affected only by the nature of cultural development. The discoveries in the Back Bay in Boston are not the only reason to beseech archaeologists to establish chronologies on a foundation which is not limited or controlled by the date of the birth of Christ. Close scrutiny of cross sections in sites and the determination of the relation of strata to those of a wide area, when combined with the minutiae of geography, can free the determination of relative and eventually absolute chronology from many stultifying factors.

These observations do not deny the significance of inferences from sequences of cultural development. Rather, it emphasizes the need for additional means of validating present concepts in the area. The so-called Archaic, for example, and the Laurentian Aspect which follows, are dated on very inadequate grounds, useful though these may be. To introduce the Dorset Culture from the Arctic Coast, to mention but one instance, which is empirically dated by the application of Eskimo chronology in which ages are referred, again empirically, to Christian chronology, in order to add weight to "guess dates" for the Archaic and Laurentian increases the difficulty of applying factors which may be more susceptible to eventual proof.

The fishweirs were constructed on a surface and eventually covered by deposits which mark episodes in a long sequence of events in eastern Massachusetts. We are concerned only with those occurring during Pleistocene time, which has been defined as that extending from the end of the Pliocene to the present. In the John Hancock excavation, as well as in many locations in the Boston Basin and surrounding areas, deposits of till, clay, sand and gravel, and a congeliturbate document the waxing and waning of glacial ice. Inclusions of Boston till are evidence of an early advance of the ice, the date and character of which is as yet inadequately known. Following this, and accompanied by cyclic changes in the level of the sea relative to the land,

there were two advances of the ice, the Boston Substage and the Lexington Substage. Evidence of the retreat of the former has been presented. The events since the latter disappeared are of particular significance.

The congeliturbate at the John Hancock excavation marks the cold period of the Lexington Substage which in other places is identified by till or outwash deposits. A layer of Rusty Sand occupied a part of the area exposed. It is thought to be the result of slope wash which deposited the sand upon the congeliturbate. Oak and maple stumps and other vegetation on the surface of this sand are evidence of an early, swamp woodland.

Resting on the congeliturbate and the Rusty Sand, where it appears, is a layer of peat. It has been shown that peat beds such as this have developed in many parts of the Boston Basin and that the location of fresh or marine varieties, and the stratification of the beds depends upon their elevation and geographic location in relation to the shores of a rising sea.

The peat bed in the Back Bay is composed of several layers, the lowest of which, comprising the major proportion of the deposit, was formed in a reed swamp and sedge-meadow. This was followed by a rather abrupt change to brackish and finally marine conditions as shown in the rapid transition to mid-tide peat dominated by *Spartina alterniflora.* It is estimated that the deposition of peat was short-lived, perhaps but one hundred years or so. At any rate, very shortly after the mid-tide grasses became established, the marine invasion increased and marine silt began to accumulate.

The sequence so sketchily outlined above is substantiated by the investigation of the pollen and diatoms. It is also easily explainable by the topography. The ancestral Back Bay had developed as a low-lying area in Post Lexington time. It was cut off from the ancient Charles River by a low-lying ridge and because of the poor drainage was wet and swampy, supporting a flora characteristic of such areas. As sea level rose it inundated the bay. This flooding was slow during the time the water ran over first one and then both of the saddles at the ends of the ridge. Eventually the sea topped the ridge to flood the Bay, giving rise to distinctly marine conditions. At some time following the inundation, when presumably conditions were suitable for fish to run into the Bay from the Charles River, the Indians constructed their fishweirs. There is little evidence of erosion of the surface of the peat, so that silting must have begun shortly after the invasion. Because of continued silting it is estimated that the fishweirs were probably not used over a long period of time. It is more likely that they were rather rapidly covered with silt which rendered them useless. These considerations are reason for questioning the lengthy periods of use postulated by Knox.[1]

[1] Knox, 1942, p. 126.

Investigation of the pollen, diatoms and to some extent the foraminifera lead to refinements of previous ideas. The change from fresh-water to marine conditions is amply documented. Ideas concerning the temperature of the water have been modified. Although inferences from the diatom population are the same as previous ideas, data from the foraminifera is food for thought. Phleger has identified forms which are not, commonly, members of the local fauna. These find their origin, he believes, in segments of Gulf Stream water which became detached from the Stream to drift onto the continental shelf and even to the coast. Thus it is necessary to reconsider the previous idea that slightly warmer waters were present and that such was evidence contributing to an opinion that the climate during Fishweir Time was slightly warmer than at present. Evidence from the pollen is another indication that the climate of the time was quite similar to that of the present day. When the pollen is sufficiently well-preserved the evidence of a flora similar to the present day is fairly clear. However this may be, I take the responsibility for suggesting that as yet we know too little to have great confidence in pollen as an indicator of minor climatic fluctuations in eastern Massachusetts, and with some important exceptions, in New England as a whole.

In commencing the present investigation it was hoped that the dates for the Fishweirs postulated by Benninghoff and Knox in 1942 might be either substantiated or refined. It is obvious that this cannot be done. The general inclination is to accept the later and more general date given by Benninghoff as late Sub-Boreal or early Sub-Atlantic. Setting a tentative period of time in this way is more consistent with our knowledge of pollen chronology in New England.

Much more of value has been presented in this volume and I commend to specialists and to others the details in the various papers. Pollen analytical methods and ingenious and important palaeobotanical techniques have been discussed, together with the details of the significant results of their application. Then too, the points of view of the various authors are either stated or implied. A consideration of these piques the curiosity of scientists and poses problems to be attacked in the future.

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